Dissolved Atmospheric Gases and Reaeration Coefficients for the Nechako River

R. D. Byres and J. A. Servizi

Department of Fisheries and Oceans
Fisheries Research Branch
Cultus Lake Research Laboratory
Cultus Lake, British Columbia V0X 1H0

June 1986

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1459

86-06376/

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457–714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715–924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of

Fisheries and Aquatic Sciences No. 1459

June 1986

DISSOLVED ATMOSPHERIC GASES AND REAERATION COEFFICIENTS FOR THE NECHAKO RIVER

by

R.D. Byres[1] and J.A. Servizi

Department of Fisheries and Oceans

Fisheries Research Branch

Cultus Lake Research Laboratory

Cultus Lake, British Columbia V0X 1H0

[1]Water Use Unit
Field Services Branch
1090 West Pender,
Vancouver, B.C.

(c)Minister of Supply and Services Canada 1986

Cat. No. Fs 97-6/1459E ISSN 0706-6457

Correct citation for this publication:

Byres, R. D. and J. A. Servizi. 1986. Dissolved atmospheric gases and reaeration coefficients for the Nechako River. Can. Tech. Rep. Fish. Aquat. Sci. 1459: 83 p.

ABSTRACT

Byres, R. D. and J. A. Servizi. 1986. Dissolved atmospheric gases and reaeration coefficients for the Nechako River. Can. Tech. Rep. Fish. Aquat. Sci. 1459: 83 p.

In June and August, 1985 field studies were conducted on the Nechako River to investigate the relationship between river discharge and reaeration coeffients (K_2). Dissolved gas and temperature data were collected, from which reaeration coefficients were calculated. The calculations included a procedure designed to account for variable gas solubilities caused by temperature changes within the "parcels" of water studied. Results are presented along with earlier data reported by the International Pacific Salmon Fisheries Commission and Envirocon Ltd, and indicate that there is a nonlinear relationship between K_2 and discharge. K_2 values for the upper reaches of the Nechako appear to increase with discharge up to a maximum value, then decrease as the discharge continues to rise. This relationship should be considered when selecting values of K_2 for modelling dissolved gas levels in the Nechako River.

RESUME

Byres, R. D. and J. A. Servizi. 1986. Dissolved atmospheric gases and reaeration coefficients for the Nechako River. Can. Tech. Rep. Fish. Aquat. Sci. 1459: 83 p.

Des études sur le terrain portant sur la rivière Nechako ont été effectuées en juin et août 1985 dans le but d'étudier les rapports entre le débit du cours d'eau et les coefficients de réaération (K_2). Ces coefficients on été calculés à partir de données recueillies sur les gaz dissous et la température. On a utilisé au cours des calculs une procédure conçue pour tenir compte de la variabilité de la solubilité des gaz découlant des modifications de température au sein des "parcelles" d'eau étudiées. Les résultats sont présentés de pair avec des données précédemment obtenues par la Commission internationale des pêches du saumon du Pacifique et Envirocon Ltd. Ils indiquent l'existence d'une relation non linéaire entre la valeur de K_2 et le débit. Dans les parties les plus en amont du cours d'eau, les valeurs de K_2 augmentent avec l'importance du débit jusqu'à une valeur maximale, mais diminuent ensuite. On devrait tenir compte de cette relation lors du choix de valeurs de K_2 pour la modélisation des teneurs de gaz dissous dans la rivière Nechako.

TABLE OF CONTENTS

Abstract iii

Introduction 1

Methodology 3

Flow Travel Times 3
Dissolved Gas Concentrations 6
Dissolved Gas Saturations and Reaeration Coefficents 7
Calculation of Total Gas Pressure values from field data . 8
Calculation of saturation concentrations 9
Calculation of reaeration coefficients (K_2) 12

Results 16

Discussion 26

References 28

Appendices 30

Government of Canada / Gouvernement du Canada
Fisheries and Oceans / Pêches et Océans

Your file *Votre référence*

Our file *Notre référence*

"The Government of Canada shall have no liability or responsibility to any person or entity with respect to any liability, loss or damage caused or alleged to be caused directly or indirectly by this software, including but not limited to any interruption of service, loss of business or anticipatory profits or consequential damages resulting from the use or operation of this software.

There is no service associated with this software and any defect or fault found therein will not be the responsibility of the Government of Canada."

Pacific Biological Station
Nanaimo, B.C.
V9R 5K6

Station de biologie du pacifique
Nanaimo, (C.-B.)
V9R 5K6

DISSOLVED ATMOSPHERIC GASES AND REAERATION COEFFICIENTS FOR THE NECHAKO RIVER

INTRODUCTION

The effects of gas supersaturation on aquatic organisms have recently become a concern on many river systems where high levels of dissolved gases occur. Gas supersaturation in water exists when the water contains dissolved gas in excess of the saturation level for the given conditions. The saturation level is mainly determined by water temperature, barometric pressure, and hydrostatic pressure. Supersaturation of a gas or gases may occur from a number of natural or man-made processes, including gas dissolution under greater-than-atmospheric pressure, heating of water, and the respiration of aquatic plants. For example, when atmospheric air is entrained deep into plunge pools below spillways or waterfalls, it is dissolved under relatively high hydrostatic pressures. When this water returns to the lower hydrostatic pressures near the surface, it is supersaturated (Weitkamp and Katz, 1980). Heating of water is a source of supersaturation because the solubility of gases decreases as water temperature rises. Thus when the temperature of saturated water rises due to thermal inputs, the water becomes supersaturated. The photosynthetic activity of aquatic plants can cause supersaturation if the production of oxygen is faster than the equilibration rate of the water (Weitkamp and Katz, 1980). Supersaturated water is unstable and the excess gas will gradually dissipate to the surrounding water or atmosphere. A curve showing gas content versus time will follow an exponential decay pattern, steepest near the vertical axis and "flattening out" as the gas level asymptotically approaches the 100% saturation level (Appendix 1).

Each constituent gas in the atmosphere exerts a measurable pressure, and the sum of such "partial pressures" is equal to the atmospheric (barometric) pressure. Similarly, each gas dissolved in water, including water vapour, will exert a pressure or "tension" proportionate to the amount of that gas dissolved. The pressure exerted by all the gases in solution is called the Total Gas Pressure (TGP). In supersaturated water, the value of TGP exceeds the barometric pressure. The difference between TGP and barometric pressure is known as the "hyperbaric dissolved gas pressure differential", or Δ P. The

ability to measure or predict TGP levels is of interest since high levels of TGP lead to formation of gas bubbles in tissues of aquatic organisms, a condition known as Gas Bubble Trauma (GBT). Refer to Alderdice and Jensen (1985) for a detailed review of GBT.

Since 1979, studies have been conducted on the Nechako River to determine existing or potential TGP levels as a consequence of supersaturation at Cheslatta Falls and warming downstream. One of these studies led to the production of a computer model which predicts TGP at downstream points given initial TGP, temperature, discharge and weather conditions (Bryan, P. unpubl. DFO 1985). This model requires values of the reaeration coefficient (K_2). A K_2 coefficient describes the rate at which an excess of dissolved gas is dissipated to the atmosphere due to turbulence. A river system with a high value of K_2 will dissipate excess gas, or "reaerate", faster than a river with a low value of K_2. Studies conducted on the Nechako during June and August 1985 were designed to collect data from which values of K_2 could be determined for various river reaches. These data, along with earlier data obtained by the International Pacific Salmon Fisheries Commission (IPSFC) and Envirocon Ltd. are combined in this report to relate K_2 in each river reach to river discharge.

METHODOLOGY

Determination of K_2 values for a given reach of a river requires knowledge of dissolved gas levels and temperatures in the same parcel of water as it passes both the upstream and downstream ends of the reach. In order to determine the sampling times at the various stations and appropriate flow times for use in the calculations, the discharge-travel time relationship must be known. The methods used are subdivided into three parts: determination of flow travel times, collection of dissolved gas and temperature data, and calculation of reaeration coefficients.

The sampling sites used in 1985 correspond to those chosen earlier by Envirocon and IPSFC as the boundaries of reaches (Figure 1). Site locations are also marked on 1:50,000 scale maps on file in the Water Use Unit at the Department of Fisheries and Oceans (DFO).

FLOW TRAVEL TIMES

Water levels were read manually at three Water Survey of Canada (WSC) stations periodically, and converted to discharges using WSC rating tables. These discharge data are considered preliminary, as WSC may revise the gauge datum or prepare a new rating curve which could alter the final discharge values (P. Langford, WSC Prince George, pers. comm.). The gauge Nechako-below-Cheslatta (STA.NO.08JA017) is linked by a Data Control Platform (DCP) to Vancouver, and field readings were supplemented by daily DCP readings from this station. The river cross section at this gauge is believed to be stable and the gauge readings are considered reliable (P. Langford, pers. comm.). The Nautley-River-near-Fort-Fraser gauge (STA.NO.08JB003) is also considered stable, located approximately 100 m above the rock berm installed by Alcan Ltd. to control the water levels on Fraser Lake. The Nechako-at-Vanderhoof gauge (STA.NO.08JC001) was a manual chain type gauge below the highway bridge but was replaced in September 1985 by a recording manometer gauge. The rating curve for this gauge is likely to be revised due

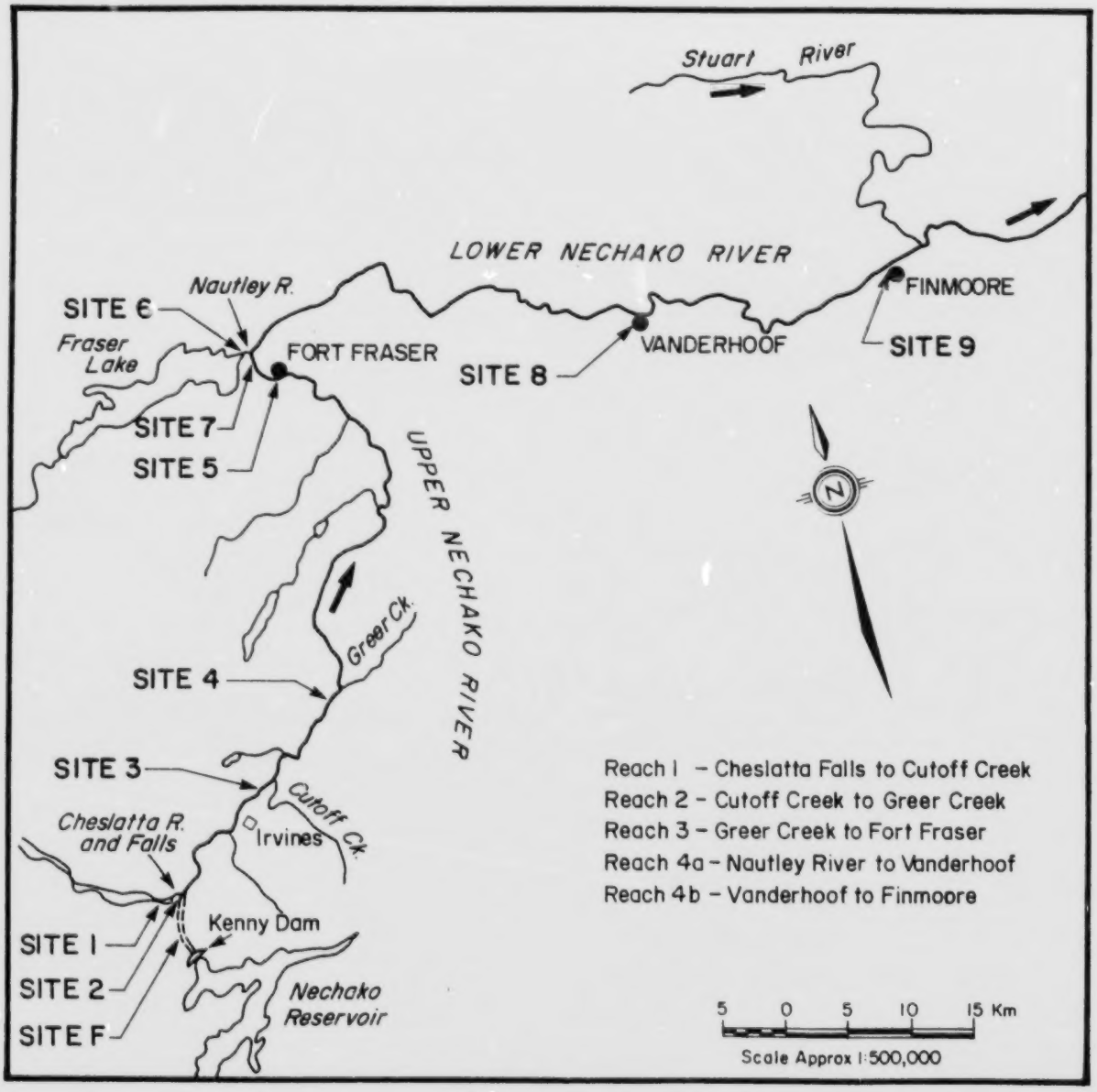


Figure 1 Nechako River TGP Sampling Sites and River Reach Boundaries

to the finer grained, more mobile bed material in this reach. The current stage/discharge relationship is approximately 6% less than the 1983 rating curve (P. Langford, pers. comm.). The hydrologic data collected during June and August 1985 are presented in Appendix 2.

Curves of discharge versus travel time were prepared using data from a hydraulic routing model (IPSFC 1979), which simulates the average river velocity at a number of discharges for each of 103 cross-sections between Cheslatta Falls and the Stuart River. Flow travel times at some discharges were based on extrapolation of IPSFC data (Envirocon 1984:a). Using these simulated velocities and the known distances between cross-sections, the travel times between the transect boundaries were calculated. The total travel time for a specific reach at a specific discharge was therefore the sum of the times for all the transects within the reach. These data are recorded in Appendix 3 and plotted on curves in Appendix 4. Travel times for discharges other than those determined by IPSFC were obtained by interpolation of curves in Appendix 4. For higher discharges the curves were extrapolated to 283 - 311 m^3s^{-1} (10000-11000 ft^3s^{-1}) since IPSFC data extended only to 198 m^3s^{-1} (7000 ft^3s^{-1}). It is estimated that little uncertainty was introduced by this extrapolation since the curves are quite regular and there was little or no overbank flooding at the higher discharges.

The measured river discharges, calculated travel times, and sampling schedule used for the TGP measurements are given in Appendices 5 - 6. The discharge was measured on the same day that the upstream station of a reach was sampled, and the flow travel time calculated to obtain the sampling times for the downstream station. If the discharge was changing from one day to the next and the flow travel time was quite long, the initial measured discharge was assumed to represent that of the entire reach sampling period.

For sampling stations between the WSC gauge locations, the discharge was assumed to be equal to that of the closest, most representative gauge. That is, for reaches 1, 2 and 3 the Nechako-below-Cheslatta gauge was used, and for reaches 4a and 4b the Nechako-at-Vanderhoof gauge was used. Refer to Figure 1 for reach boundaries and sample locations. With the exception of the Nautley River, contributions from tributaries between the gauges were approximately 5.7 m $^3s^{-1}$ (200 ft $^3s^{-1}$) or 2 to 10% of the total discharge, and were not included in the calculation of flow travel times.

DISSOLVED GAS CONCENTRATIONS

For a given discharge, three "parcels" of water were sampled at one-hour intervals at the upstream boundary of each reach. The three parcels were again sampled as they passed the downstream boundary of the reach, according to elapsed times determined from the discharge-travel time curves (Appendix 4).

Water samples were collected at the sites shown in Figure 1. In some instances the August sites did not correspond exactly to those used in June. These changes were necessary since at the higher flows of August some of the original locations were unsuitable or inaccessible due to dense brush along the river bank. The error in elapsed time associated with the slight changes in site was considered negligible.

The raw data required for calculating dissolved gas concentrations included water temperature, total gas pressure, barometric pressure, and dissolved oxygen content. Water temperatures were measured using calibrated total immersion thermometers accurate to 0.1°C, held 5-10 cm below the water surface and shielded from direct sunlight. Sampling was done > 1 m away from the shore, to avoid lower water velocities and shallow depths at the river edge. Local barometric pressures were measured using a Paulin altimeter (model A1) and applying a conversion formula (eq. 1). Δ P measurements were made with two Novatech tensionometers (models 300B and 300C) and dissolved oxygen was measured using the Winkler procedure (field techniques are outlined

in Appendix 7). Sampling sites were selected to ensure that well-mixed water was sampled, usually > 1 m from the edge effects near the shoreline. Tensionometers were allowed to equilibrate in air for approximately five minutes before the readings were set to zero and the probes immersed in the river. When it was uncertain whether equilibrium had been reached, a graph of TGP versus time was plotted to define the equilibrium value of TGP (see Appendix 8). Slow drift of Δ P was not major and was generally within the $\pm$ 2 mm Hg accuracy of the instrument. Such variation was possibly attributable to the unusually high and variable barometric pressure experienced during sampling. In discussion with Novatech staff (Mr. Korman) a change of < 1 mm Hg in barometric pressure is insufficient to require re-zeroing the instrument. At his suggestion, the probe was left in the water for each three-hour sampling period during the August survey.

DISSOLVED GAS SATURATIONS AND REAERATION COEFFICIENTS

Values of K_2 were calculated for each reach using data obtained at the upstream and downstream ends of the reach for a specific parcel of water. The process of converting field measurements to estimates of K_2 involved a series of three calculations. First, TGP values and the relative contributions from oxygen and the other atmospheric gases were calculated in the field, using the raw data sheets (Appendix 9). It was assumed that oxygen, nitrogen and argon were the only gases in solution, the contribution of other trace gases being negligible (Colt 1983). (For practical purposes the behaviour of nitrogen and argon in solution are the same, and these were therefore considered as one gas.) The second calculation determined the temperature-dependent saturation concentrations of N_2+Ar, and converted the gas concentrations into convenient units of milligrams per litre (mgL^{-1}). Finally, reaeration coefficients were calculated for each reach using gas concentrations at each end of the reach and the corresponding travel times and temperatures.

Calculation of TGP values from field data

Barometric pressure was determined using a conversion specific to the Paulin altimeter:

$$(1) \quad BP = (30.0 - \frac{\text{Altimeter Reading}}{933.3}) \ 25.4 \text{ mm Hg}$$

Percent Total Saturation (moist air) was often used interchangeably with TGP since it was more convenient to refer to TGP as a relative percentage supersaturation rather than a value in pressure units, and was calculated as follows:

$$(2) \quad TGP \text{ (moist)} = \frac{(BP + \Delta P)100}{BP} \ \%$$

where Δ P is the equilibrium reading on the tensionometer. Percent Saturation in dry air was calculated the same way, except that the contribution of water vapour pressure (WVP) was substracted (Colt 1983):

$$(3) \quad TGP \text{ (dry)} = \frac{(BP-WVP + \Delta P)100}{BP} \ \%$$

Water vapour pressure is temperature dependent and was obtained from Colt (1984).

Partial Pressure of Oxygen was determined by (Colt 1983):

$$(4) \quad P_{[O_2]} = \frac{DO \ (0.5318)}{B_{[O_2]}} \qquad \text{mm Hg}$$

where DO = dissolved oxygen from Winkler test (mgL^{-1})

$B_{[O_2]}$ = Bunsen coefficient for Oxygen

Bunsen coefficients were generated from the following regression equations (after Weiss, 1970):

$$(5)\quad \ln B_i = A_1 + A_2\,(100/T) + A_3 \ln\left(\frac{T}{100}\right) + \text{Salinity terms}$$

where T = absolute termperature (°C + 273.15);

A_i = constants specific for each gas (see Appendix 10); and

B_i = Bunsen coefficient for each gas.

Salinity terms were neglected since fresh water was tested.

Percent saturation of oxygen was determined as follows (Colt 1983):

$$(6)\quad \%O_2 = \frac{100\ P[O_2]}{(BP-WVP)(0.2095)}\ \%$$

Partial pressure and percent saturation of N_2 + Ar were based on subtracting all other gas contributions from the total (Colt 1983):

$$(7)\quad P_{[N_2+Ar]} = BP + \Delta\ P - WVP - P_{[O_2]}\ \text{mm Hg}$$

$$(8)\quad \%\ [N_2+Ar] = \frac{100\ P_{[N_2+Ar]}}{(BP-WVP)(0.79018)}\ \%$$

The above calculations were performed in the field using a programmable hand calculator and the results checked before proceeding.

Calculation of saturation concentrations

For a given temperature and barometric pressure there is a saturation concentration for each dissolved gas. The solubility of a gas at saturation is equal to its Bunsen coefficient multiplied by the partial pressure of that gas in the atmosphere. For the combined N_2+Ar gas a weighted mean calculation was used to obtain ambient and saturation concentrations (Colt 1983):

$$(9)\quad \text{Concentration of } N_2+Ar\,(mgL^{-1}) = P_{[N_2+Ar]}\,\frac{B_{[N_2+Ar]}}{A_{[N_2+Ar]}}$$

where $B_{[N_2+Ar]}$ is the Bunsen coefficient for N_2+Ar

$$(10)\quad B_{[N_2+Ar]} = \frac{(0.78084)B_{[N_2]} + (0.00934)B_{[Ar]}}{0.79018},$$

and

$$(11)\quad A_{[N_2+Ar]} = \frac{760}{1000}\left[\frac{(0.78084)B_{[N_2]} + (0.00934)B_{[Ar]}}{(0.78084)K_{[N_2]}\,B_{[N_2]} + (0.00934)K_{[Ar]}\,B_{[Ar]}}\right]$$

Where 0.78084, 0.00934, and 0.79018 are the mole fractions of N_2, Ar, and N_2 + Ar respectively;

$K_{[N_2]}$ and $K_{[Ar]}$ are the ratios of molecular weight to molecular volume for N_2 and Ar respectively (Appendix 10)

(Since the mole fraction of Argon is very small compared to that of Nitrogen, the Argon terms do not significantly affect the calculations. For calculating K_2, the contribution of Argon can be neglected and equations (10) and (11) can be approximated using only Nitrogen. Similarly, saturation concentrations and K_2 coefficients for N_2 + Ar can be approximated as those for N_2 alone.)

Saturation concentrations of gases were obtained by using the following regression equations (after Weiss 1970):

$$(12)\quad CS_i(mg/l) = CS_i(ml/l)K_i(mg/ml)$$

$$(13)\quad \ln CS_i(ml/l) = A_1 + A_2\left(\frac{100}{T}\right) + A_3 \ln\left(\frac{T}{100}\right) + A_4\left(\frac{T}{100}\right) + \text{salinity terms}$$

where T = absolute temperature (°C + 273.15)

CS_i = solubility of i^{th} gas at STP

A_i = constants (see Appendix 10)

K_i = ratio of molecular weight to volume (Appendix 10)

Salinity terms neglected for fresh water.

Finally, the saturation concentration of N_2+Ar is (Colt 1984):

(14) $CS_{[N_2+Ar]} = CS_{[N_2]} + CS_{[Ar]}$

These values are only valid for an atmospheric pressure of 760 mm Hg. The results were therefore corrected for the local barometric pressure as follows (Standard Methods 1976):

(15) $CS_{[N_2 + Ar]}(local) = CS_{[N_2 + Ar]} \frac{(BP-WVP)}{(760-WVP)}$

Calculation of reaeration coefficients (K_2)

The following development of K_2 calculations has been largely extracted from Servizi (1981):

Using the Streeter-Phelps (1925) expression for the "oxygen sag" equation, reaeration is expressed in terms of supersaturation as follows:

(16) $S_1 = S_0 10^{-k_2 t}$

where S_1 = percent saturation exceeding 100% at Station 1
S_0 = percent saturation exceeding 100% at Station 0
t = flow travel time between stations, (hours)
k_2 = reaeration coefficient based on $\log_{10}$ (hr^{-1})

The value of k_2 represents the rate at which excess dissolved gas is dissipated to the atmosphere due to turbulence. The higher the value of k_2, the faster gas transfer occurs. The values of dissolved gas saturation are also influenced by barometric pressure and temperature.

In addition to turbulence, temperature, and barometric pressure, values of dissolved oxygen saturation levels are affected by biochemical oxygen demand (BOD) and the respiration of aquatic plants and algae. To avoid these biological influences, calculation of k_2 was based on changes in nitrogen and argon concentrations only. The value of k_2 is related to the inverse ratio of the molecular diameters of oxygen and nitrogen (Tsivoglou et al. 1965, 1968), and therefore k_2 for oxygen can be calculated from k_2 for nitrogen and argon as follows:

(17) $k_{2[O_2]} = 1.068 k_{2[N_2+Ar]}$

Rearranging equation 2-16 and solving for k_2 yields:

(18) $k_2 = -\frac{1}{t} \log_{10} \frac{(S_1)}{(S_0)}$

To evaluate k_2 for a particular river reach, S_0, S_1 and t must be known. The calculated value of k_2 corresponds to the temperature at which sampling was done. Reaeration coefficients determined at one temperature can be converted for another as follows (Dysart 1970):

(19) $k_2(T) = k_2(20)(1.024^{T-20})$

where $k_2(20)$ is the value of the reaeration coefficient at 20°C, and

T is the local temperature (°C).

Conversely, rearranging equation (19) allows k_2 at field temperatures to be converted to a common base of 20°C for comparison purposes:

(20) $$k_2(20°C) = \frac{k_2(T)}{1.024^{T-20}}$$

Equations (16), (18), (19) and (20) are based on the assumption that temperatures remain constant over the reach. In practice this is rarely the case, and mean temperatures are not theoretically acceptable substitutes for constant temperatures when calculating values of k_2.

A method of calculation was developed which corrects for temperature changes between stations (Servizi 1981). This method was applied to IPSFC and DFO data (August, October 1980, and June, August 1985) as follows:

> If the temperature of the water increases between sampling stations, dissolved gases become less soluble. This causes a tendency to reduce the gas content more rapidly than if temperatures had remained constant, thereby overestimating the value of k_2. The reverse occurs if the temperature decreases downstream. Since the tendency for change in gas content is an exchange reaction, it can be expressed as follows:

(21) $\Delta_1 = \Delta_0 10^{-k_2 t}$

where Δ_0 = the difference between 100% saturation of nitrogen plus argon at the two stations at prevailing temperatures and pressures (mgL^{-1})

Δ_1 = the portion of the difference remaining to be exerted (mgL^{-1})

t = flow travel time between stations (hr)

k_2 = reaeration coefficient as in equation (16) (hr^{-1})

The change in nitrogen plus argon concentration actually exerted due to temperature change will be $\Delta_0 - \Delta_1$, expressed as "d". Substituting this into equation (21) yields:

$$d = \Delta_0 - \Delta_1 = \Delta_0(1-10^{-k_2 t}) \tag{22}$$

If the temperature does not change between stations, the value of this expression is zero and no correction is needed.

When supersaturated water flowing in a river undergoes a temperature change the nitrogen and argon content observed at the downstream station will be the net result of gas exchanges due to both reaeration and temperature change. If the temperature increases, the gas content measured will be less than if the temperature had remained constant. To obtain the gas content that would have resulted had the temperature been constant (i.e. due to reaeration only), the decrease due to temperature rise must be added to the measured value at the downstream end. The value of this correction is equal to "d" in equation (22) above. Since this correction removes the effect of temperature change from the gas content at the downstream station, the percent saturation (S_1 in equation (16)) is calculated by comparing the corrected downstream gas content with the upstream saturation concentration.

To calculate k_2, an estimated value of k_2 would be used in equation (22) to calculate a value of "d". The measured downstream concentration of nitrogen and argon would be corrected by this

amount, and using the corrected value, S_1 would be determined. A new value of k_2 would then be calculated using equation (18) and the result compared with the original estimate. Trial and error bring the estimated and calculated values into agreement.

Values of k_2 calculated by the trial-and-error temperature correcting method used a fixed-point iteration method algorithm adapted for computer. Convergence to a final value was possible for most data pairs, except where the temperature differences between upstream and downstream ends of the reach exceeded approximately 2.5°C. For these cases, a modified version of the secant method (see Appendix 11) produced satisfactory results. The latter method has since been adapted to the Apple II computer since it converges well for almost all data pairs. A sample hand calculation using the trial-and-error method is included for reference (Appendix 12).

Values of k_2 were converted form $\log_{10}$ to $\log_e$ as follows:

$$(23)\quad K_2(\text{base}_e) = \frac{k_2(\text{base } 10)}{0.43429}$$

This final step was performed to enable comparison of K_2 values with other values previously published (IPSFC 1979, Envirocon 1984:b). (Note that upper-case K_2 refers to the "base e" form of the coefficient, while the lower case version refers to the "base 10" form.)

RESULTS

The field data and TGP values measured during June and August 1985 are summarized in Appendices 2-6 and 13-14, attached.

Dissolved gas data collected in June and August 1985 indicate that supersaturation increased by approximately 4% after passing over Cheslatta Falls at 62.3 m^3s^{-1} (Table 1). Samples A, B, C, and 114 indicate supersaturation increased approximately 10 to 12% due to Cheslatta Falls at 289 m^3s^{-1}. Since measurements above Cheslatta Falls indicate similar levels of supersaturation at both 62.3 and 289 m^3s^{-1}, this suggests that the amount of supersaturation downstream of Cheslatta Falls increases with discharge. At both discharges, values of TGP observed to decrease to near "background" levels when the water reached Vanderhoof (samples 34, 128).

The effect of temperature on supersaturation was demonstrated by samples 15 and 18 (Table 1). Although the dissolved gas content decreased between Cutoff Creek and Greer Creek, a temperature rise of 3.4°C resulted in an increase in % TGP from 103.1% to 107.9%. Such variation in water temperature and supersaturation was more pronounced during June than in August due to the lower flows during June.

Measurements near the base of Cheslatta Falls on August 8, 1985 were variable and were not used to calculate K_2 (Appendix 5). These measurements were taken directly at the base of the Falls and indicated a variable supersaturation of 110-112%, while the downstream values at Cutoff Creek were recorded as more than 113% at almost the same temperature and barometric pressure. In addition, a sample taken approximately 200 m downstream of the Falls on August 2 had a TGP value near 115%. Consequently, to assure data were representative of the effects of the falls on TGP, a site approximately 500 m downstream of the falls was chosen, which produced consistent TGP values near 115%. It seemed apparent that much of the gas dissolution took place downstream of the initial sampling location at the base of the falls.

At least three parcels of water were followed in each reach to obtain values of K_2 (Table 2). For reach 4a at 138 m^3s^{-1} (4870 ft^3s^{-1}), samples 31, 32, and 35 were combined with 30 to yield flow-weighted mixed samples (Appendicies 15, 16). This was necessary since the Nautley River (sample 30) contributed a significant portion of the total flow for reach 4a. Similarly, at 311 m^3s^{-1} (11,000 ft^3s^{-1}) samples 122, 123, 124 were combined with 125 to yield starting conditions for reach 4a. Combining the samples at 138 m^3s^{-1} resulted in a starting gas content lower than at the downstream end, and thus K_2 for reach 4a could not be calculated at 138 m^3s^{-1}. Mean values of K_2 were calculated for each reach (Table 3) using values of K_2 from Table 2 with two exceptions. For reach 1 at 62.3 m^3s^{-1} (2,200 ft^3s^{-1}) and for reach 3 at 289 m^3s^{-1} (10,200 ft^3s^{-1}), values of 0.043 and 0.173, respectively, were well outside the data trends (Figs. 2a and 2c) and were excluded from the means. Values of K_2 reported earlier by IPSFC and Envirocon Ltd. (Table 4) for each parcel of water in each reach were plotted with data from Table 2 to give curves of K_2 versus river flow (Figs. 2a, 2b and 2c) and these were combined in Figure 2d. Although values of K_2 were obtained only at 311 m^3s^{-1} for reaches 4a and 4b, (as well as 138 m^3s^{-1} for reach 4b), tentative curves were proposed with curvatures similar to reach 3 since these reaches appear physically similar. In each case the curves were fit visually to the data.

Table 1. Selected Values of Nechako River Dissolved Gas Data
June and August, 1985

Sample No.	Location	Discharge m^3s^{-1}	Date DY/MO	Time 24 Hr.	Water Temp (°C)	Dissolved O_2 mgL^{-1}	Dissolved N_2+Ar mgL^{-1}	% TGP (moist air)
1	Above Ches. Falls	62.3	15/06	0935	12.5	9.95	16.86	102.7
2	Below Ches. Falls	62.3	15/06	1100	12.4	10.25	17.81	106.8
6	Cutoff Cr.	62.3	15/06	1630	14.4	10.40	16.91	106.8
9	Cutoff Cr.	62.3	16/06	0800	10.7	10.25	17.95	102.8
12	Greer Cr.	62.3	16/06	1645	14.7	10.20	17.01	107.6
15	Cutoff Cr.	62.3	17/06	0800	11.7	10.20	17.60	103.1
18	Greer Cr.	62.3	17/06	1545	15.1	10.00	16.92	107.9
24	Ft. Fraser	62.3	15/06	1500	16.8	9.50	15.81	105.6
34	Vanderhoof	138	20/06	0912	15.5	9.15	15.82	100.8
A*	Above Falls	289	07/08	1430	16.6	-	-	105.6
B*	Above Falls	289	09/08	1315	16.2	-	-	104.3
C*	Above Falls	289	11/08	1330	16.0	-	-	103.0
114	Below Falls	289	10/08	1245	16.3	10.20	17.83	115.2
117	Cutoff Creek	289	10/08	1640	16.4	10.20	17.30	112.6
128	Vanderhoof	311	13/08	0115	16.7	8.75	15.62	103.0

* Samples A, B and C were collected as part of a separate experiment (Rowland 1986). They were not numbered and no dissolved oxygen measurements were made.

TABLE 2: REAERATION COEFFICIENTS FOR THE NECHAKO RIVER
(DERIVED FROM DISSOLVED GAS DATA, JUNE AND AUGUST, 1985)

DISCHARGE ft^3s^{-1}	DISCHARGE m^3s^{-1}	REACH 1 $K_2(20°C)_e$	REACH 1 Data Pair	REACH 2 $K_2(20°C)_e$	REACH 2 Data Pair	REACH 3 $K_2(20°C)_e$	REACH 3 Data Pair
2200	62.3	0.137	(2,6)	0.082	(10,12)	0.041	(18,24)
		0.043	(3,7)	0.089	(11,13)	0.039	(19,25)
		0.077	(4,8)	0.054	(15,18)	0.036	(20,26)
				0.060	(16,19)		
				0.076	(17,20)		
10200	289	0.061	(112,115)	0.043	(103,106)	0.059	(106,109)
		0.063	(113,116)	0.036	(104,107)	0.063	(107,110)
		0.066	(114,117)	0.036	(105,108)	0.173	(108,111)

DISCHARGE ft^3s^{-1}	DISCHARGE m^3s^{-1}	REACH 4a $K_2(20°C)_e$	REACH 4a Data Pair	REACH 4b $K_2(20°C)_e$	REACH 4b Data Pair
4870	138	-	(31,34)	0.028	(21,27)
		-	(32,35)	0.030	(22,28)
		-	(33,36)	0.014	(23,29)
11000	311	0.078	(122,126)	0.030	(126,129)
		0.055	(123,127)	0.025	(127,130)
		0.042	(124,128)	0.029	(128,131)

Reach 1: Cheslatta Falls - Cutoff Creek
Reach 2: Cutoff Creek - Greer Creek
Reach 3: Greer Creek - Fort Fraser
Reach 4a: Nautley River confluence - Vanderhoof
Reach 4b: Vanderhoof - Finmoore

TABLE 3: AVERAGE VALUES OF K_2(20°C) BASED ON 1985 DATA (NECHAKO RIVER)

DISCHARGE m^3s^{-1}	DISCHARGE ft^3s^{-1}	REACH 1	REACH 2	REACH 3	REACH 4a	REACH 4b
62.3	2200	0.107	0.072	0.039	-	-
138	4870	-	-	-	-	0.024
289	10200	0.063	0.038	0.061	-	-
311	11000	-	-	-	0.058	0.028

TABLE 4: SUMMARY OF $K_2(20°)$ (NITROGEN) REPORTED BY IPSFC AND ENVIROCON LTD. (Base e)

DISCHARGE m^3s^{-1}	REACH 1	REACH 2	REACH 3++
32 *	0.0744	0.0300	0.0300
	0.0816	0.0300	0.0300
	0.0845	0.0390	0.0345
	0.0845	0.0437	0.0345
	0.0960		0.0368
			0.0391
Mean	0.0840	0.0360	0.0340
170 **	0.0722+	0.0444+	0.0493
	0.1412	0.0650	0.0500
	0.1423	0.0705	0.0530
	0.1480	0.0778	0.0557
	0.1568	0.0868	0.0675
Mean	0.1471	0.0750	0.0554
252 ***	0.0299	0.0493	0.0459
	0.0333	0.0532	0.0481
	0.0358	0.0567	0.0566
	0.0378	0.0699	0.0569
	0.0557	0.0872	0.0595
Mean	0.0358	0.0667	0.0539

* IPSFC, collected Oct. 1980, adjusted to correspond to same reaches as Envirocon.

** Envirocon, collected July 22-23, 1982 (from Envirocon 1984:b)

*** Envirocon, collected Aug. 5-6, 1982 (from Envirocon 1984:b)

\+ value not used in calculating mean since outside trend of data (see Fig. 2a and 2c).

++ Reach 4a, K_2, ($K_2(20°)$ equal to $0.04h^{-1}$ at 55 $m^3s^{-1}m$ Aug. 1980.

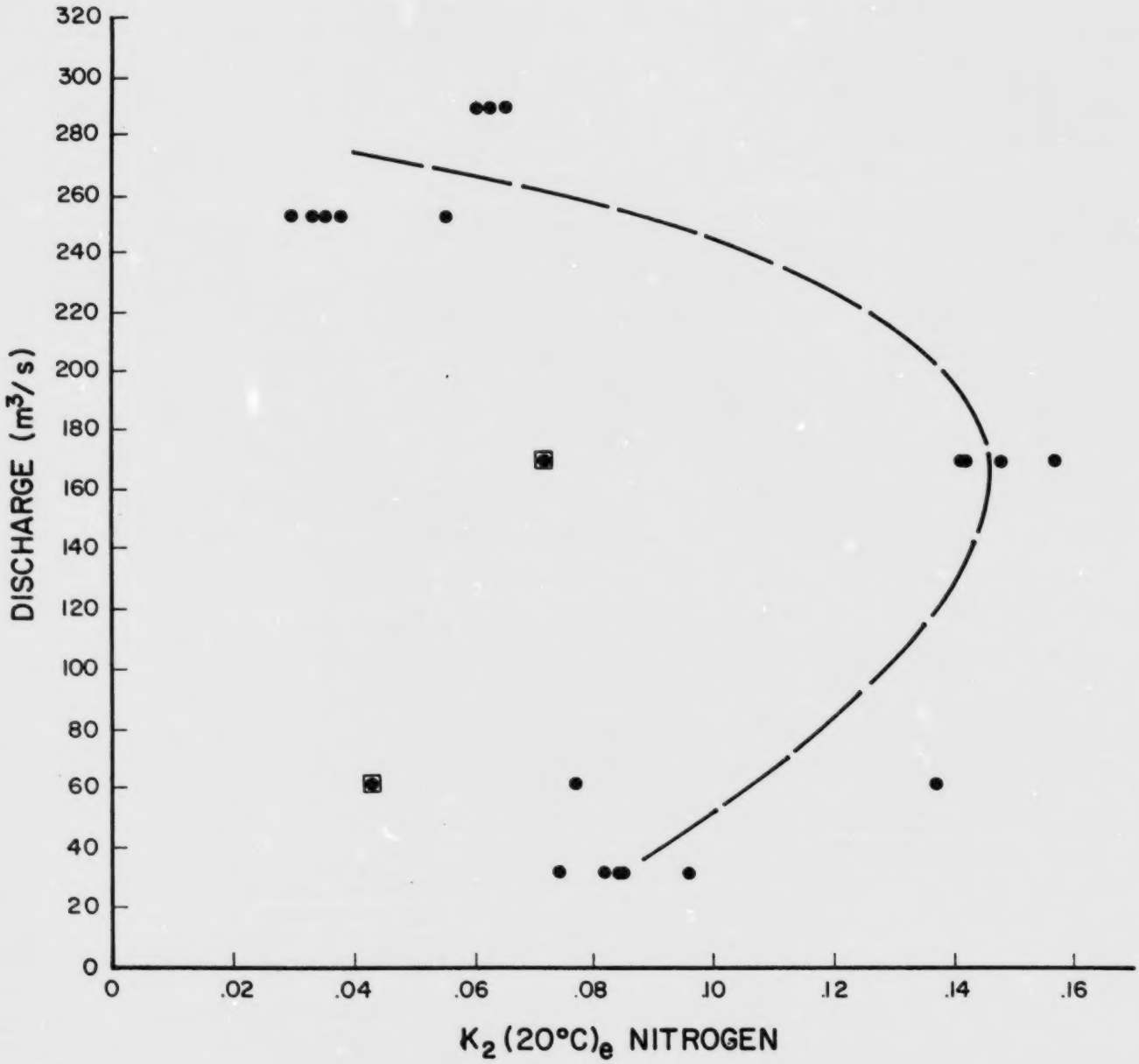


Figure 2a Reaeration Coefficients (K_2) vs Discharge - Nechako River Reach 1 - Cheslatta Falls to Cutoff Creek

▣ Indicates value not used to calculate mean K2

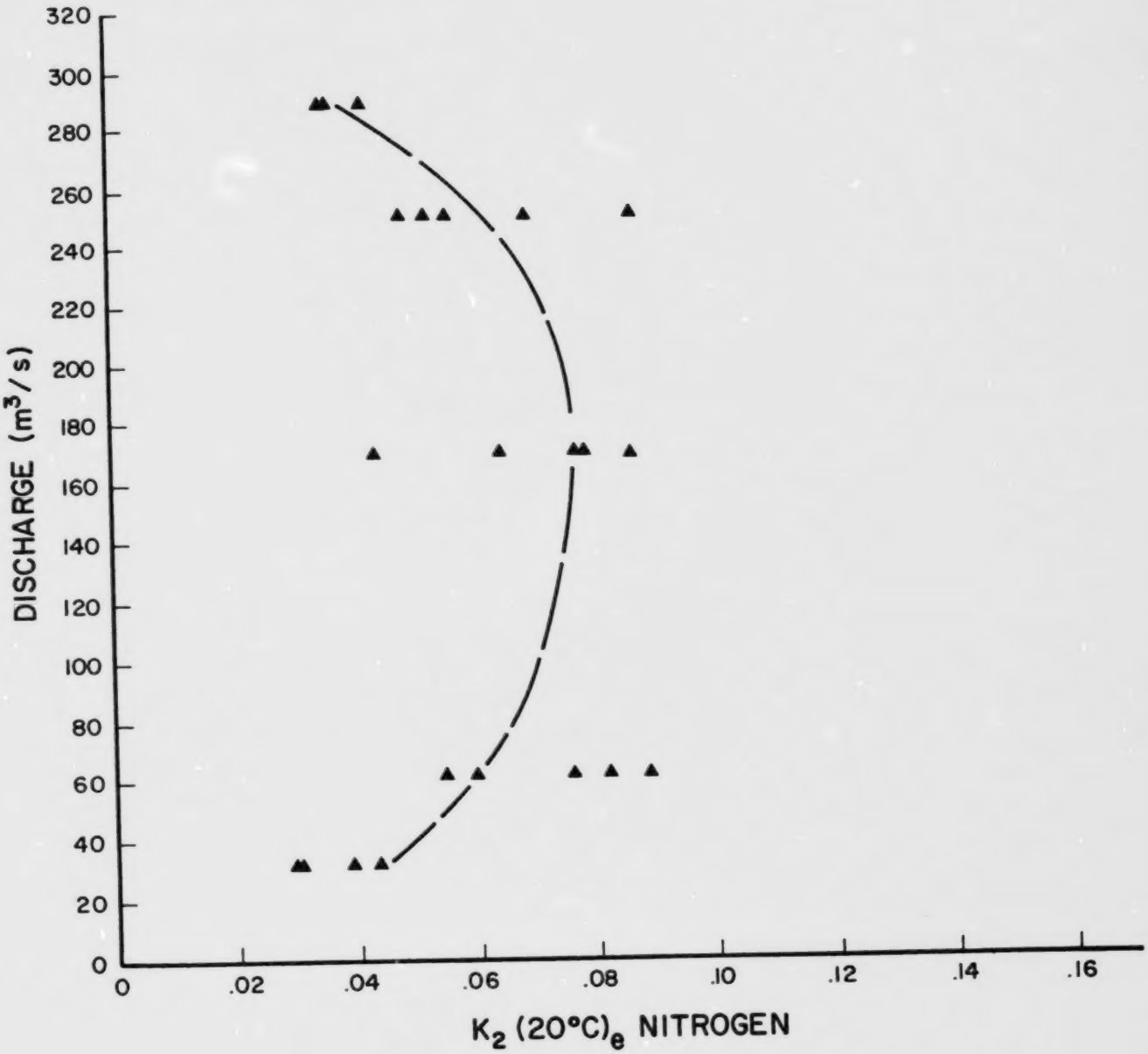


Figure 2b Reaeration Coefficients (K_2) vs Discharge – Nechako River Reach 2 – Cutoff Creek to Greer Creek

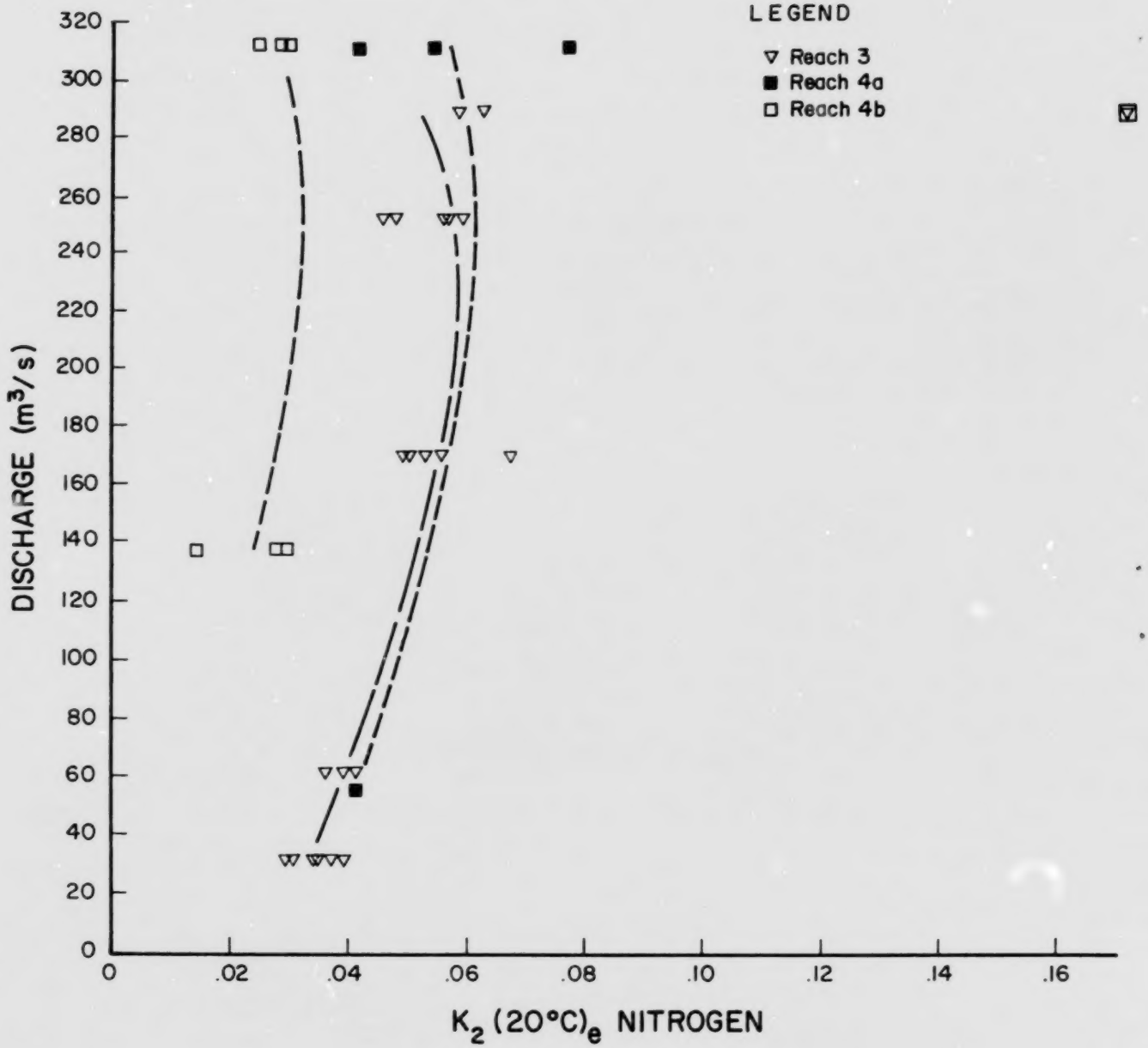


Figure 2c Reaeration Coefficients (K_2) vs Discharge – Nechako River Reach 3 – Greer Creek to Ft. Fraser, Reach 4a – Nautley to Vanderhoof, Reach 4b – Vanderhoof to Finmoore

☒ Indicates value not used to calculate mean K_2

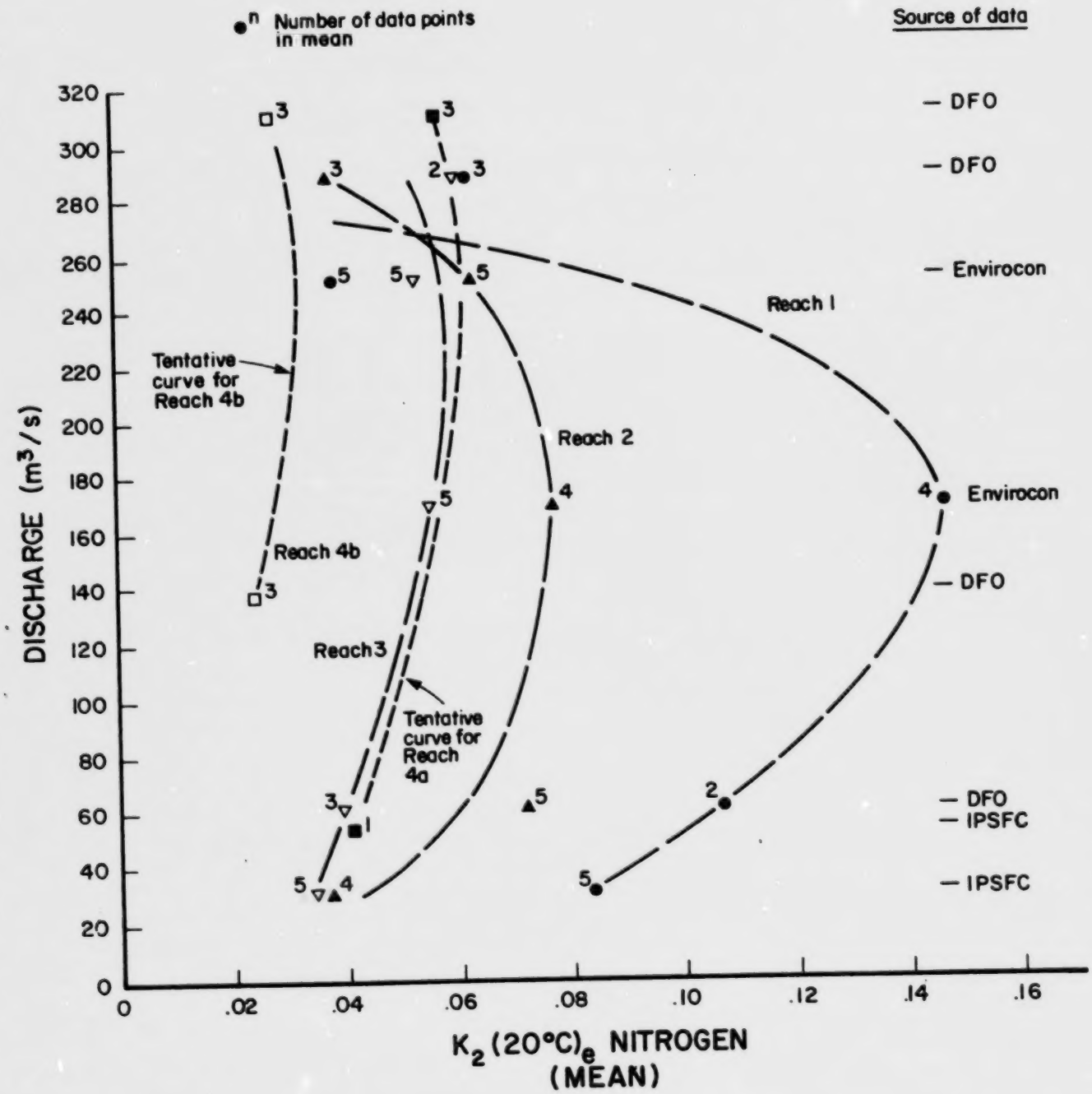


Figure 2d Reaeration Coefficients (K_2) vs Discharge – Nechako River

DISCUSSION

For reaches 1 and 2, reaeration coefficients demonstrate a flow dependent relationship where K_2 increases with discharge then diminishes as the discharge continues to increase (Figure 2d). This appears reasonable since K_2 is dependent on the amount of turbulence which is in turn affected by the river morphology. At lowest flows the water exhibits less turbulence at constrictions and riffles, but as discharge increases the amount of mixing and turbulence increases. At very high flows many of the former riffles are inundated and turbulence decreases, thereby reducing gas exchange at the surface. This flow-dependent effect would be more pronounced in the upper, more turbulent reaches of the river than in the lower reaches where the gradient is lower. The curves in Figure 2d support this observation, with the most pronounced variation of K_2 with flow occurring in reach 1.

When fitting curves in Figures 2a through 2c, four pieces of data were evidently outside the general trend of the data. Since values of K_2 were derived from field measurements, some experimental error can be expected. Flow travel time is one possible source of error. Determination of K_2 was based on the assumption that the same parcel of water was sampled at both upstream and downstream stations. The average flow travel times used to identify passage of the parcels of water were based on channel morphology surveys that were up to 30 years old. Although a recent partial re-survey has established that parts of the bed configuration have not changed significantly, no tests were made to confirm accuracy of flow travel times. However, tests of the sensitivity of K_2 to travel time indicate errors of about 9-11% for a variation of ±10% in travel times. (Appendix 17) Temperature is another possible source of error. Temperature measurements influence K_2 because temperature determines the gas solubility and degree of saturation of the water. Measurements were generally made 1-2 metres from the bank, within 5-10 cm of the surface. Since the river was continually mixed due to turbulence and since temperatures were measured in "well moving" areas of water, errors associated with temperature measurement would be small.

Nonetheless, sample calculations indicate the an error of ±0.2°C in temperature measurement would result in an error of about 8% in the calculated value of K_2 for reach 1 (see Appendix 18).

The most pronounced variation of K_2 with discharge occurs in reach 1. This reach is important to fish protection, since it is in reach 1 that GBT may occur due to the high values of TGP immediately downstream of Cheslatta Falls. In addition, during summer heating and depending on river disharge, TGP may be elevated in downstream reaches as temperatures rise faster than TGP decreases due to reaeration. Such predictions must rely on mathematical modelling of temperature and TGP. For these reasons account must be taken of the relationship between river flow and K_2 when modelling TGP in the Nechako River.

REFERENCES

Alderdice, D.G., and Jensen, J.O.T. 1985. Assessment of the Influence of Gas Supersaturation on Salmonids in the Nechako River in Relation to Kemano Completion. Can. MS Rep. Fish. Aquat. Sci. No. 1386: 48p.

Bryan, Patrick. 1985. Oxygen and Nitrogen Gas Level Simulation Model. Program documentation and users manual. Unpublished report, Dept. Fisheries and Oceans.

Colt, J.E. 1984. Computation of Dissolved Gas Concentrations in Water as Functions of Temperature, Salinity, and Pressure. Am. Fish. Soc. Spec. Publ. 14, Bethesda, Maryland.

Colt, J.E. 1983 The Computation and Reporting of Dissolved Gas Levels. Water Resources, Vol. 17, No. 8, pp.841-849, Great Britain.

Dysart, B.C. III. 1970 Water Quality Planning in the Presence of Interacting Pollutants. J. Water Pollut. Control Fed. 42(8): 1515.

Envirocon Ltd. 1984:a. Environmental Studies associated with the Proposed Kemano Completion Hydroelectric Development. Vol. 2, Sec. A. Appendix A3.1: 1682.

Envirocon Ltd. 1984:b. Environmental Studies associated with the Proposed Kemano Completion Hydroelectric Development. Vol. 2, Appendix C2: 394p.

Hamilton, K. and Bergersen, P. 1984. Methods to Estimate Aquatic Habitat Variables. Colorado Cooperative Fisheries Research Unit, Colorado State University, for Bureau of Reclaimation.

International Pacific Salmon Fisheries Commission. February, 1979. Salmon Studies associated with the potential Kemano II hydroelectric development. Vol. 2 Sockeye salmon studies on the Nechako River.

Moore, W.J. 1972. Physical Chemistry, 4th ed., Prentice Hall, Englewood Cliffs, New Jersey, U.S.A.

Rowland, D.E. 1986. 1985 Nechako River field Studies - Gas Bubble Trauma in Salmonids. (unpubl. DFO)

Servizi, J.A. 1981. Estimation of reaeration coefficients for the Nechako River. Int. Pac. Salmon Fish. Comm. Data Analysis, Part II. January, 1981. 8pp.

Standard Methods for the Examination of Water and Wastewater. 1976. Am. Pub. Health Ass. Washington, D.C.

Streeter, H.W. and E.B. Phelps. 1925. A study of the pollution and natural purification of the Ohio River. Bulletin 146, U.S. Pub. Health Service, reprinted 1958.

Tsivoglou, E.C., R.C. O'Connell, C.M. Walter, P.J. Godsil and G.S. Logsdon. 1965. Tracer measurements of atmospheric reaeration - I. Laboratory studies. J. Water Pollut. Control Fed. 37(10): 1343.

Tsivoglou, E.C., J.B. Cohen, S.D. Shearer, P.J. Godsil. 1968. Tracer measurements of stream reaeration - II. Field Studies. J. Water Pollut. Control Fed. 40(2): 285. Part 1.

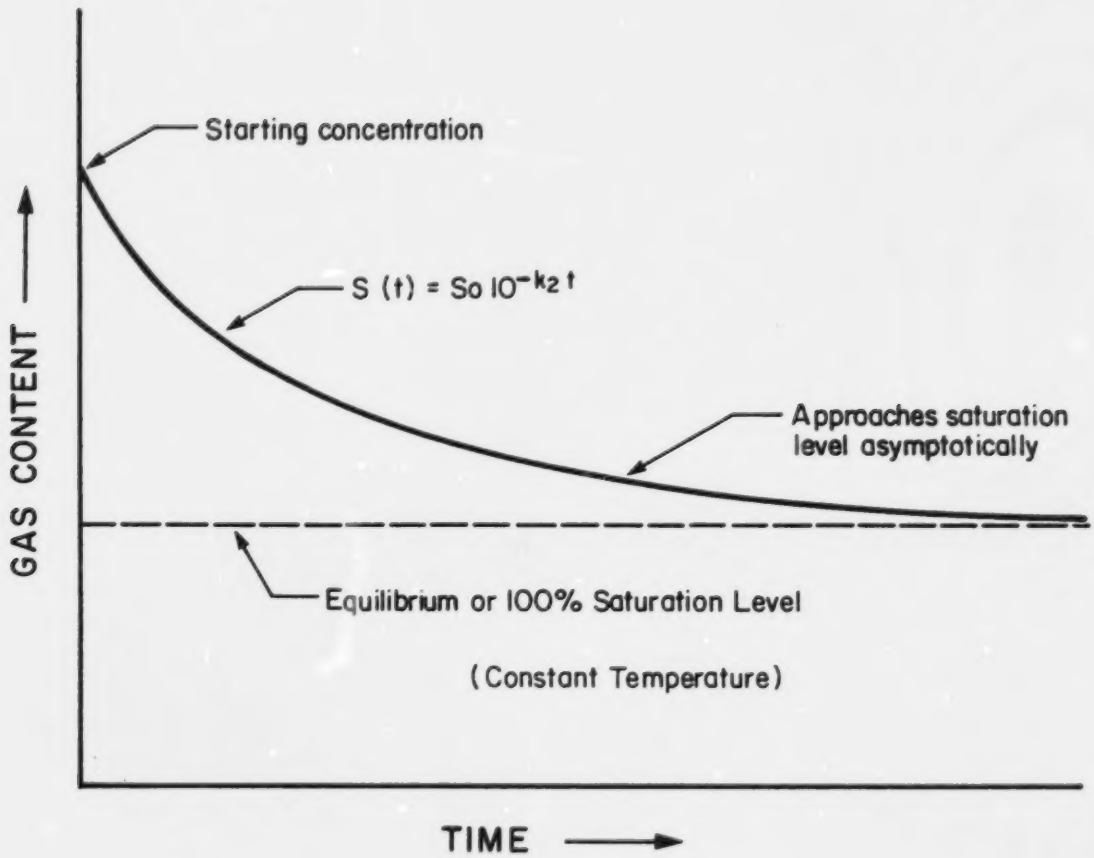
Weast, R.C. (ed.) 1974. Handbook of Chemistry and Physics, 55th Ed., CRC Press, Cleveland, Ohio.

Weiss, R.F. 1970. The solubility of nitrogen, oxygen and argon in water and seawater. Deep-Sea Research, 17: 721-735.

Weitkamp, D.E. and Katz, M. 1980. A Review of Dissolved Gas Supersaturation Literature. Trans. Am. Fish. Soc. 109: 659-702.

APPENDICES

1. Gas Supersaturation vs. Time plot; showing qualitative behavior of dissolved gas.
2. Hydrologic Data, June and August 1985
3. Travel Time for Nechako River at Various Discharges
4. Discharge vs. Travel Time Curves
5. Flow Travel Times and Sampling Schedule, June 1985
6. Flow Travel Times and Sampling Schedule, August 1985
7. Winkler Test field Procedures
8. Δ P vs. Time plot; showing equilibrium tensionometer reading.
9. Dissolved Gas Survey Data Sheet
10. Coefficients for Calculation of Bunsen Coefficients and Gas Solubilities
11. K_2 Computer Program Description and User's Instructions.
12. Sample Calculations - Reaeration Coefficients
13. Dissolved Gas Data, June 1985
14. Dissolved Gas Data, August 1985
15. Flow-Weighted Mixing Criteria Applied for Reach 4a
16. Sample Calculation - Flow-Weighted Mixing
17. Sensitivity of K_2 to Travel Time Variability
18. Sensitivity of K_2 to Temperature Measurement



Appendix I Gas Supersaturation vs Time (Qualitative)

APPENDIX 2

HYDROLOGIC DATA

Station	Date Day/Mo/Yr.	Time 24 hr.	Stage (m)	Discharge (m^3s^{-1})	Discharge (ft^3s^{-1})
Nechako-below-Cheslatta Falls (Irvine's) (WSC Sta.No.08JA017)					
	5/6/85	2400*	0.82	64.0	2260
	11/6/85	2400	0.81	62.1	2195
	14/6/85	2400	0.81	62.1	2195
	15/6/85	1530	0.814	62.8	2218
	16/6/85	1050	0.811	62.2	2197
	17/6/85	1045	0.809	61.8	2182
Nechako-at-Vanderhoof (WSC Sta.No.08JC001)					
	15/6/85	1126	2.403	144	5085
	18/6/85	0945	2.349	138	4873
	19/6/85	1220	2.232	126	4450
	20/6/85	0855	2.327	136	4803
Nautley R.-near-Ft. Fraser (WSC Sta.No.08JB003)					
	15/6/85	1240	1.035	75.2	2656
	19/6/85	1545	0.975	67.4	2380
Irvine's					
	6/8/85	0723	1.735	288	10170
	7/8/85	0900	1.741	289	10206
	8/8/85	+	1.750	292	10312
	9/8/85	+	1.748	291	10276
	10/8/85	0937	1.738	289	10206
	11/8/85	+	1.738	289	10206
	12/8/85	+	1.732	287	10135
Vanderhoof					
	12/8/85	1220	3.697	312	11018
Nautley					
	11/8/85	0830	0.528	23.6	833

* 2400 readings have been obtained from WSC Vancouver office using the DCP - telemark system, and are read only to the nearest two decimal points.

\+ readings marked (+) were obtained from published WSC data listing mean daily readings from DCP system.

APPENDIX 3

TRAVEL TIMES FOR NECHAKO RIVER AT VARIOUS DISCHARGES (TIMES GIVEN IN DECIMAL HOURS) BASED ON IPSFC FLOW ROUTING MODEL

REACH	DISCHARGE ft^3s^{-1} 1,000	1,500	2,000	3,000	4,000	5,000	7,000
CHESLETTA - CUTOFF CR.	7.94	6.54	5.83	5.04	4.63	4.40	4.09
	7.94	6.54	5.85	5.04	4.64	-	-
CUTOFF CR. - GREER CR.	11.35	9.14	8.04	6.92	6.35	6.02	5.68
	11.35	9.14	8.05	6.92	6.35	-	-
GREER CR. - FT. FRASER	34.55	27.71	24.21	20.60	18.19	16.82	15.15
	34.59	27.75	24.25	20.61	18.24	-	-
FT. FRASER - NAUTLEY R.	7.61	5.91	5.08	4.20	3.73	3.46	3.12
	7.62	5.93	5.09	4.20	3.61	-	-
NAUTLEY R. - VANDERHOOF	35.28	28.52	24.90	20.94	18.86	17.51	15.91
	35.28	-	24.92	21.05	18.83	17.52	-
VANDERHOOF - FINMOORE	63.06	46.00	37.36	28.59	24.04	21.29	18.18
	62.89	-	37.35	28.56	24.04	21.31	-

Upper values from Envirocon Ltd. 1984:A

Lower values are from data published in IPSFC, February 1979, (Shown for comparison)

Where only one value is shown, it is based on extrapolation of IPSFC data by Envirocon.

APPENDIX 4

DISCHARGE VS FLOW TRAVEL TIME CURVES
(Based on data from Appendix 13)

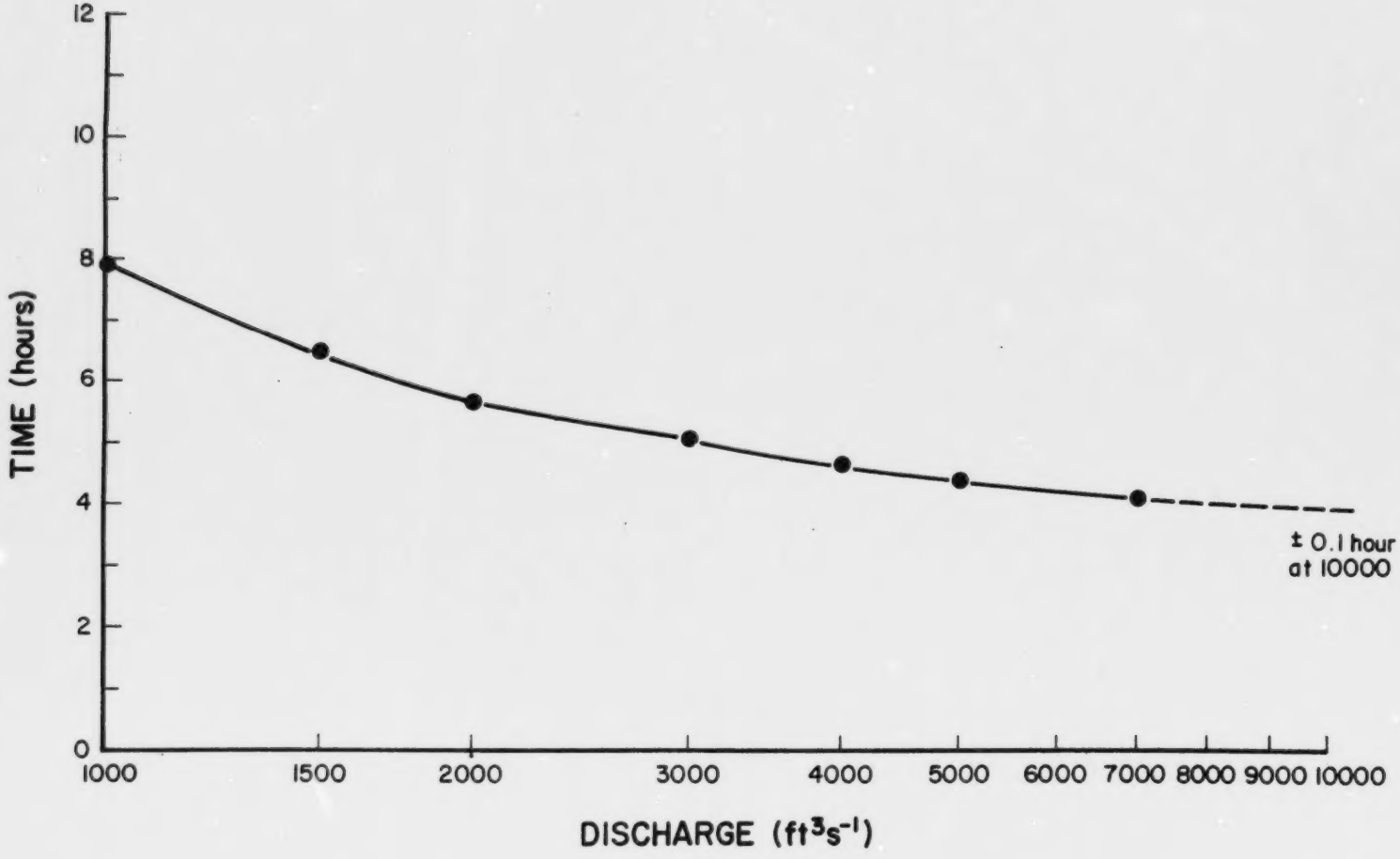


Figure A1 Discharge vs Travel Time on Nechako River
Cheslatta Falls - Cutoff Creek

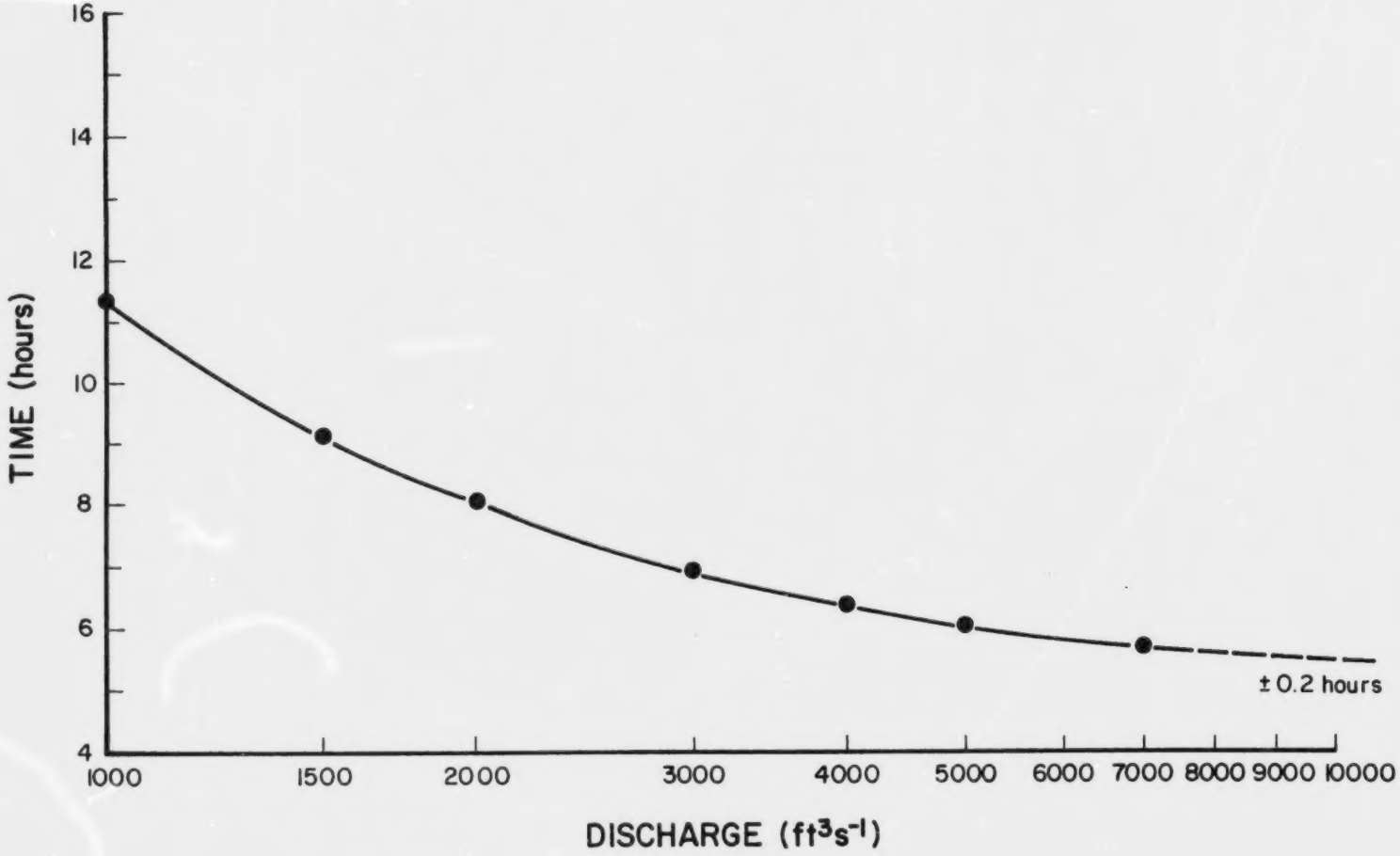


Figure A2 Discharge vs Travel Time on Nechako River
Cutoff Creek – Greer Creek

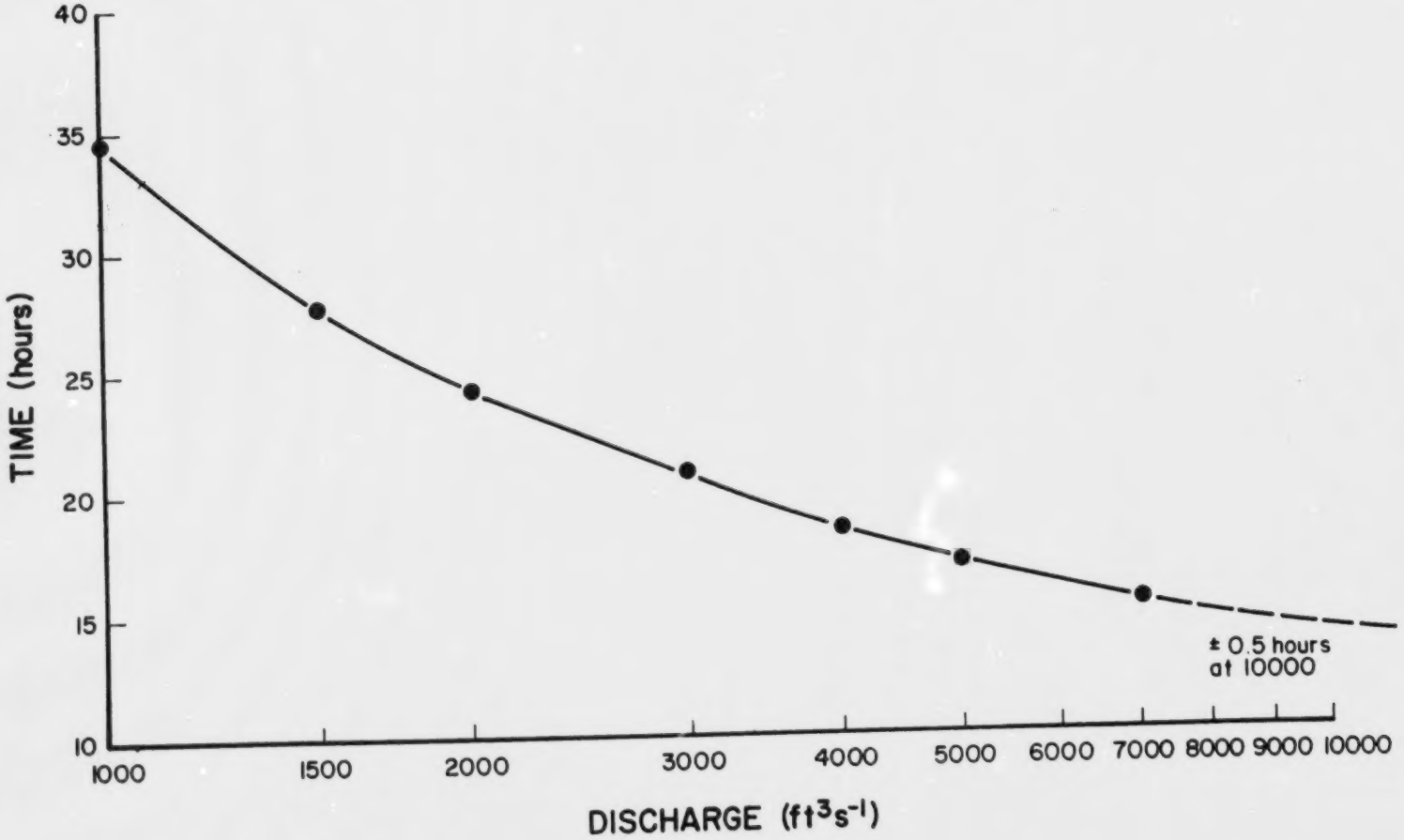


Figure A3 Discharge vs Travel Time on Nechako River
Greer Creek – Fort Fraser

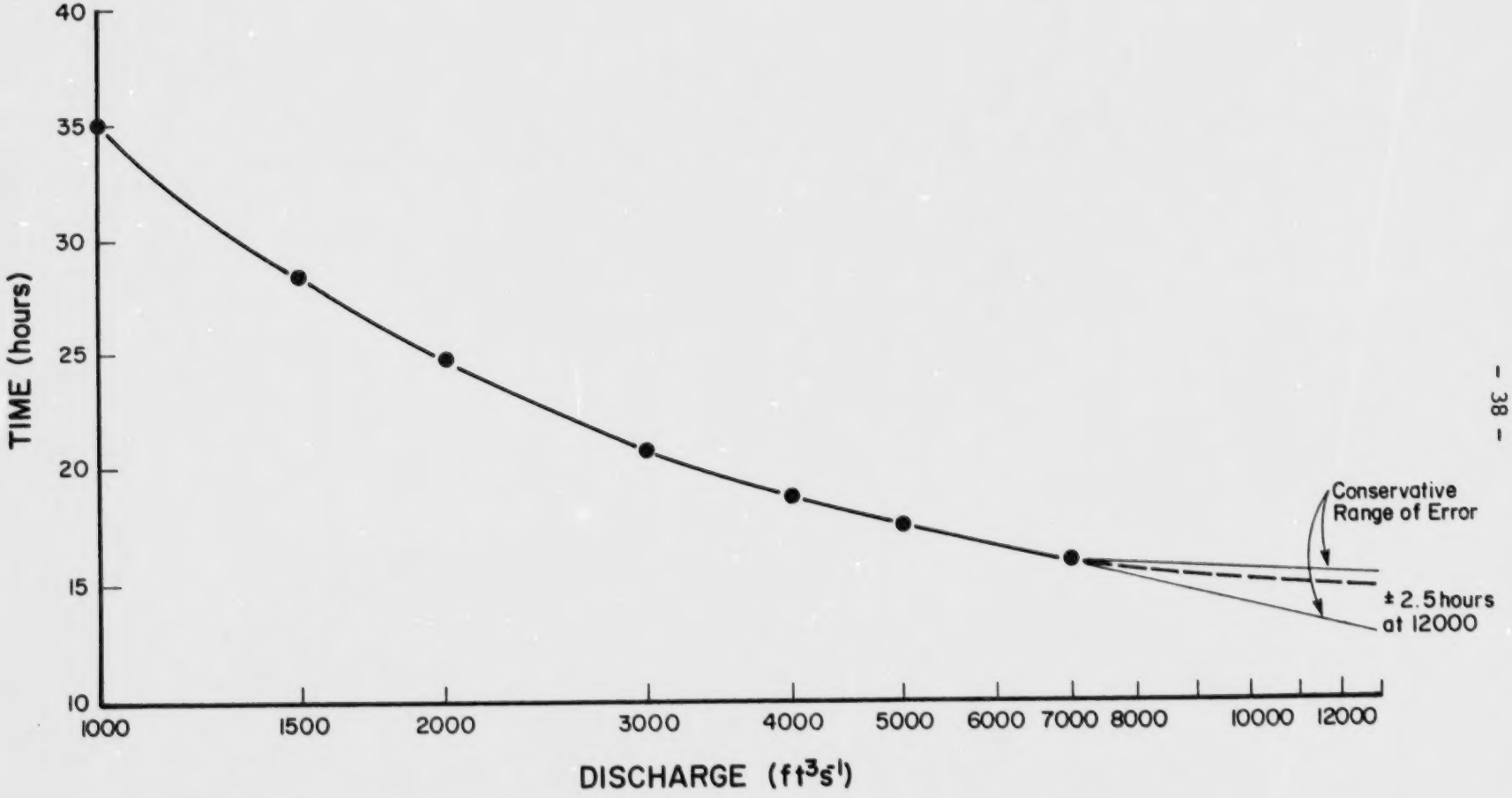


Figure A4 Discharge vs Travel Time on Nechako River
Nautley River – Vanderhoof

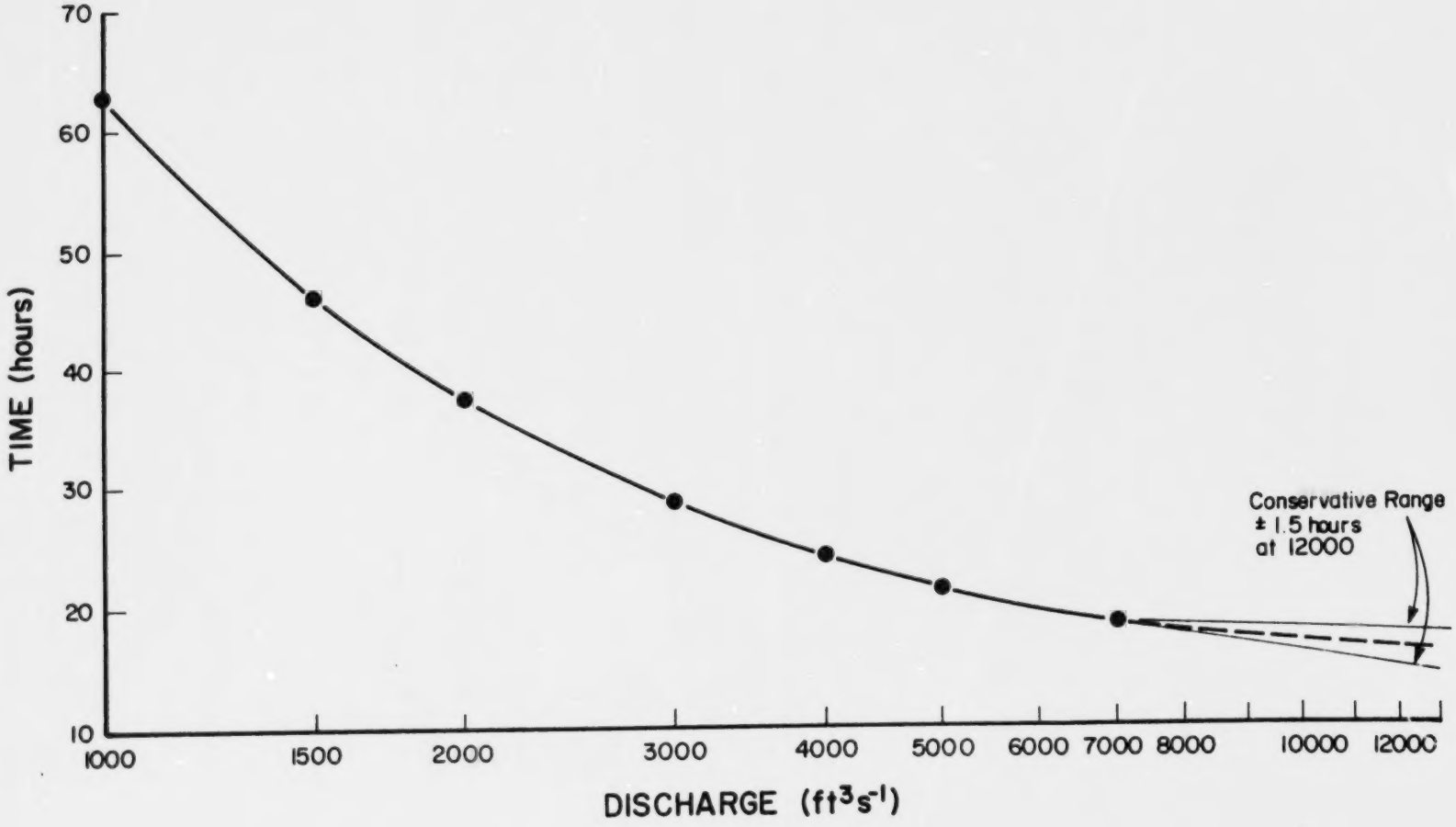


Figure A5 Discharge vs Travel Time on Nechako River
Vanderhoof – Finmoore

APPENDIX 5

FLOW TRAVEL TIMES AND SAMPLING SCHEDULE BY REACH, JUNE 15-20, 1985

	Reach	Discharge (ft^3s^{-1})	Flow Travel Time (hrs)	Station	Sample Dates and Times
1.	Cheslatta - Cutoff	2195 at Irvine's	5.5	Cheslatta Flats	15 JN; 1100, 1200, 1300
				Cutoff Creek	15 JN; 1630, 1730, 1830
2.	Cutoff - Greer	2195 at Irvine's	7.75	Cutoff Creek	17 JN; 0800, 0900, 1000
				Greer Creek	17 JN; 1545, 1645, 1745
3.	Greer - Ft. Fraser	2195 at Irvine's	23.25	Greer Creek	17 JN; 1545, 1645, 1745
				Ft. Fraser	18 JN; 1500, 1600, 1700
4a.	Nautley - Vanderhoof	4450 at Vanderhoof	18.2	Nautley	19 JN; 1500, 1600, 1700
				Nechako	19 JN; 1400
				Vanderhoof	20 JN; 0912, 1012, 1112
4b.	Vanderhoof - Finmoore	4873 at Vanderhoof	21.5	Vanderhoof	18 JN; 1130, 1230, 1330
				Finmoore	19 JN; 0900, 1000, 1100

APPENDIX 6

FLOW TRAVEL TIMES AND SAMPLING SCHEDULE BY REACH, AUGUST 8-13, 1985

Reach	Discharge $ft^3s^{-1}(m^3s^{-1})$	Flow Travel Time (hrs)	Station	Sample Dates and Times
1. Cheslatta - Cutoff	10206 (289) at Irvine's	3.90	Cheslatta	10 Aug; 1045, 1145, 1245
			Cutoff	10 Aug; 1440, 1540, 1640
2. Cutoff Greer	10206 (289) at Irvine's	5.50	Cutoff	8 Aug; 1254, 1354, 1454
			Greer	8 Aug; 1824, 1924, 2024
3. Greer - Ft. Fraser	10206 (289) at Irvine's	14.80	Greer	8 Aug; 1824, 1924, 2024
			Ft. Fraser	9 Aug; 0912, 1012, 1112
4a. Nautley - Vanderhoof	11018 (312) at Vanderhoof	14.90	Nechako	12 Aug; 0820, 0920, 1020
			Nautley	12 Aug; 1100
			Vanderhoof	12-13 Aug; 2315, 0015, 0115
4b. Vanderhoof - Finmoore	11018 (312) at Vanderhoof	16.25	Vanderhoof	12-13 Aug; 2315, 0015, 0115
			Finmoore	13 Aug; 1530, 1630, 1730

APPENDIX 7

WINKLER PROCEDURE (Dissolved Oxygen)
(From Hamilton & Bergersen (1984) and IPSFC staff)

1. Read water temperature to the nearest 0.1°C, using total immersion calibrated thermometer.

2. Rinse a standard BOD bottle a few times, and gently fill with no turbulence. Cap underwater and keep cool (use bucket of cold water or ice in hot weather).

3. Inject 2 ml manganous sulphate using automatic pipette into sample, submerging tip of pipette. Rinse pipette. Recap bottle.

4. Inject 2 ml alkaline azide using auto pipette into sample, submerging tip of pipette. Rinse pipette. Recap bottle and tip off excess.

5. Shake 25 times, allow floc to settle 1/2 of bottle, then shake again and allow flow to settle.

6. Inject 2 ml sulfuric acid using auto pipette. Allow it to run down the inside of the bottle, do not submerge tip of pipette.

7. Shake 25 times.

8. Fill burette with standard 0.025 normal sodium thiosulphate. Results will be read directly in mgL^{-1} dissolved oxygen (watch tightness of fit on burette stopcock; do not allow leakage).

9. Fill volumetric flask to 203 ml from BOD bottle by inverting flask, shake all air bubbles out.

10. Titrate by adding thiosulphate drip by drip to iodine until "light straw" colour achieved.

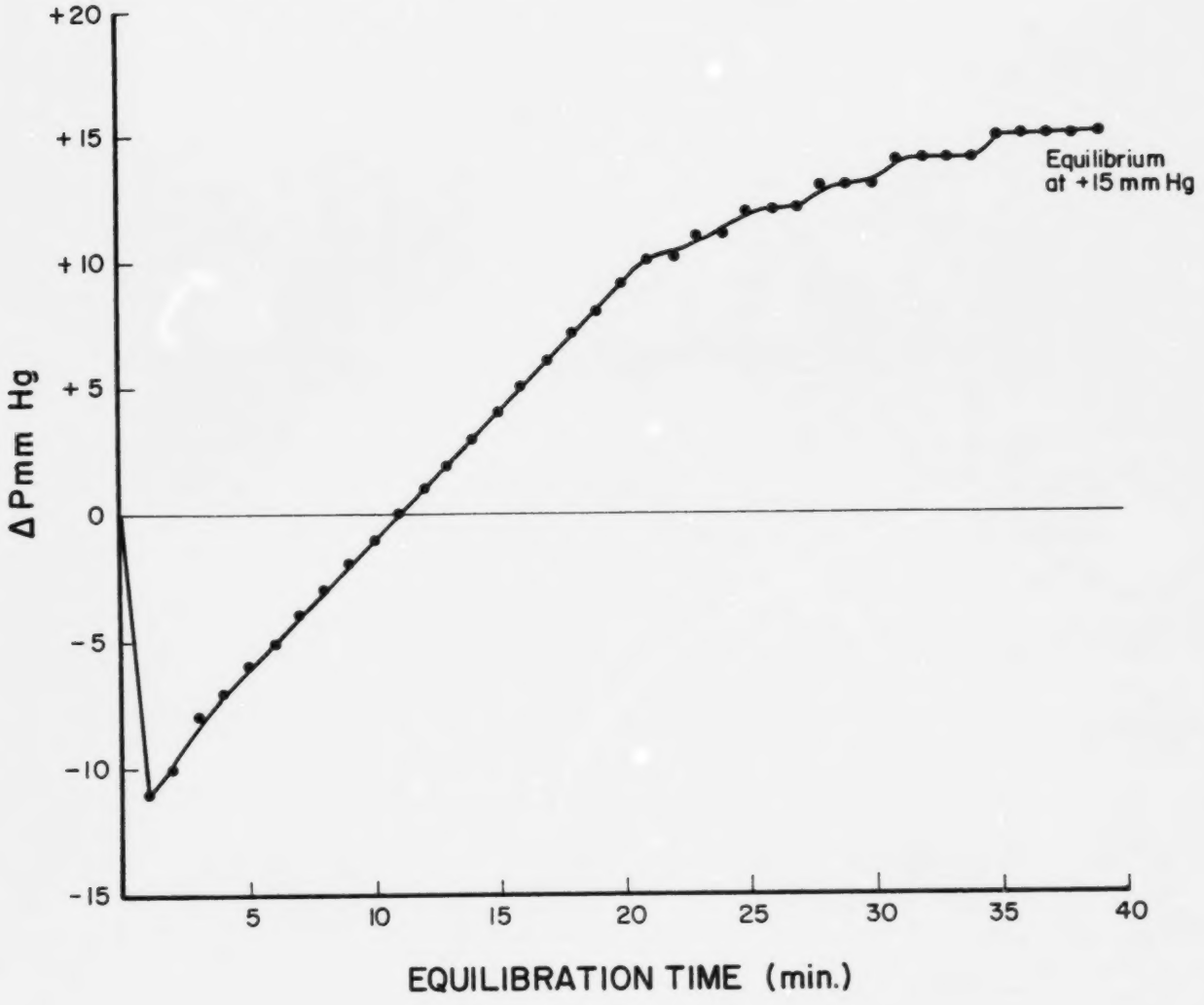
11. Add 2 ml starch.

12. Add very small amount of thiosulphate (usually few drips) until iodine clears (all trace of blue disappears) and reaches end point. Mixture should stay clear for more than 20 seconds and then gradually turn blue again. If it turns blue within 20 seconds, then add 1/2 drop.

13. Read amount of thiosulphate used in titration, to nearest .05 ml, yields mgL^{-1} dissolved oxygen.

14. Do two Winkler tests. If the difference between the tests exceeds .1 ml, conduct a third test.

15. Record time, weather (including wind), etc. at time of tests on survey sheet (Appendix 6).



Appendix 8 Tensionometer Equilibration Curve
(Novatech Ltd. Model 300B)

APPENDIX 9

DISSOLVED GAS SURVEY Sample # _____

Site _____
Date _____
Time _____
Weather _____
Depth _____
Aneroid _____(ft.)
Water Temp. _____(C°)
D.O. Winkler _____(mg/l)

Pressure Measurement
Instrument: Model # _____
Serial # _____
Probe in water @ _____
Time Δ P (mm Hg)
_____
_____
_____
_____
_____

Calculations: Final Δ P = _____ mm Hg

$$B.P. = (30.00 - \frac{An}{933.3})\ (25.4)^{a} = _____ \text{ mm Hg}$$

$$\% \text{ Total sat. (moist)} = \frac{(BP + \Delta P)\ 100}{BP} = _____ \%$$

$$\% \text{ Total sat. (dry)} = \frac{BP - WVP + \Delta P}{BP} = _____ \%$$

$$P[O_2] = \frac{D.O.(mg/l)\ (0.5318)}{\text{Bunsen coeff. } (O_2)} = _____ \text{ mm Hg}$$

$$\% O_2 = \frac{P[O_2]\ (100)}{(BP - WVP)\ (0.2095)} = _____ \%$$

$$P[N_2 + Ar] = BP + \Delta P - WVP - P[O_2] = _____ \text{ mm Hg}$$

$$\% N_2 + Ar = \frac{P[N_2 + Ar]\ (100)}{(BP - WVP)\ (0.79018)} = _____ \%$$

[a]. Conversion specific to Paulin altimeter.
Other formulae taken or derived from Colt (1984): Computation of Dissolved Gas Concentrations in Water as Functions of Temperature, Salinity, and Pressure. Amer. Fish. Soc. Special Pub. No. 14 Bethesda, Maryland.

APPENDIX 10

Constants for calculation of Bunsen Coefficients (Moore 1972/Weiss 1970, 1974)

CONSTANT	OXYGEN	NITROGEN	ARGON
A1	-58.3877	-59.6274	-55.6478
A2	85.8079	85.7661	82.0262
A3	23.8439	24.3696	22.5929
Ki	1.42903	1.25043	1.78419

Constants for calculation of Gas Solubilities (Weiss 1970)

CONSTANT	OXYGEN	NITROGEN	ARGON
A1	-173.4292	-172.4965	-173.5146
A2	249.6339	248.4262	245.4510
A3	143.3483	143.0738	141.8222
A4	-21.8492	-21.7120	-21.8020

APPENDIX 11

REAERATION COEFFICIENTS COMPUTER PROGRAM
DESCRIPTION AND USER'S INSTRUCTIONS

This appendix has been included for reference purposes and is intended to "stand on its own" for users who wish to use the following program to calculate values of the reaeration coefficient (K_2).

Calculations involved are those listed in the Methodology section of this report. This appendix contains the following:

1.	DESCRIPTION	of program and data requirements, as well as the Secant Method root-finding procedure.
2.	USERS INSTRUCTIONS	for operating the program on Apple II computers.
3.	PROGRAM LISTING	of computer code in Applesoft BASIC. The program is documented with REMark statements for the reader's convenience.

Reaeration Coefficients Computer Program
Documentation and Users Instructions.

Description

This program uses dissolved gas data collected from a natural river system to determine values of the reaeration coefficient (k_2) which appears in the Streeter-Phelps gas relaxation equation as follows:

$$S_1 = S_0 10^{-k_2 t} \qquad (1)$$

where S_1 = dissolved gas content in excess of 100% saturation at station 1 (mgL^{-1}).

S_0 = dissolved gas content in excess of 100% saturation at station 0 (mgL^{-1}).

k_2 = reaeration coefficient, hr^{-1}, based on $\log_{10}$

t = flow travel time between stations.

Using this equation enables one to predict dissolved gas levels downstream of some initial station, once accurate values of K_2 and travel time are known.

Rearranging equation (1) and solving for K_2 yields:

$$k_2 = -\frac{1}{t} \log_{10}\left[\frac{S_0}{S_1}\right] \qquad (2)$$

This program requires that dissolved gas levels (S_0, S_1) and flow travel time (t) are known. In addition, the program also uses a temperature-correcting method (J. Servizi 1981) which accounts for variable gas solubilities due to temperature changes within a reach. The original trial-and-error solution method has been replaced with a version of the secant method, which is described below. Refer to the calculations section of "Dissolved Atmospheric Gases and Reaeration Coefficients for the Nechako River" (Byres and Servizi 1986) for a complete description of the formulae used.

To calculate a value of k_2 for a given reach, the user requires the field data for the upstream and downstream samples, as well as the flow travel time between stations. Specifically, the following are required as input data:

Discharge	in m^3s^{-1} or ft^3s^{-1}
Reach number	(if more than 1 reach is used)
Sample numbers	(arbitrarily assigned to samples)
Dissolved oxygen	(from Winkler test, for greater accuracy) (mgL^{-1})

Barometric pressure	(from Aneroid reading or barometer) (mmHg)
Tensionometer reading	(equilibrium value) (mmHg)
Travel time between stations	(in decimal hours)

To facilitate data entry for a large number of samples, the user should arrange the raw data sheets in numerical order according to the assigned sample numbers, and have a separate sheet showing discharge and flow travel time for each upstream/downstream data pair. The latter list is particularly useful if some samples correspond to both the downstream end of one reach and the upstream end of the subsequent reach.

Secant Method Root-Finding Algorithm

This program uses a version of the Secant Method to find the root of the trial-and-error procedure of determining K_2.

To simplify the following discussion, assume that the functions f(x) and g(x) are defined as follows:

$$f(x) = -\frac{1}{t}\log_{10}(g(x)) - x$$

$$g(x) = \frac{\frac{100}{S_0}\left[C_1 + (S_0 - S_1)(1-10^{-xt})\right] - 100}{\frac{(100)C_0}{S_0} - 100}$$

Where C_0, C_1, S_0, S_1, and t are constants. (These equations represent the calculation of k_2 from dissolved gas data)

A graph of x versus f(x), that is, a plot showing the estimate of k_2 versus the difference between estimated and calculated values will produce a downward sloping curve similar to that shown in Figure (19). The point where the curve crosses the horizontal axis is the point where the estimated and calculated values are the same, i.e. where their difference is equal to zero. The secant method finds this point quickly and reliably provided the user supplies initial bounds which are "close" to the root sought. It is not necessary for the initial bounds to contain the actual root if the curve is "well behaved" in the vicinity of the root (i.e. there are no discontinuities, local maxima or minima, or inflection points). For practical cases involving dissolved gas data this condition appears to be true. The problem therefore is to find the solution to f(x) = 0 on some interval.

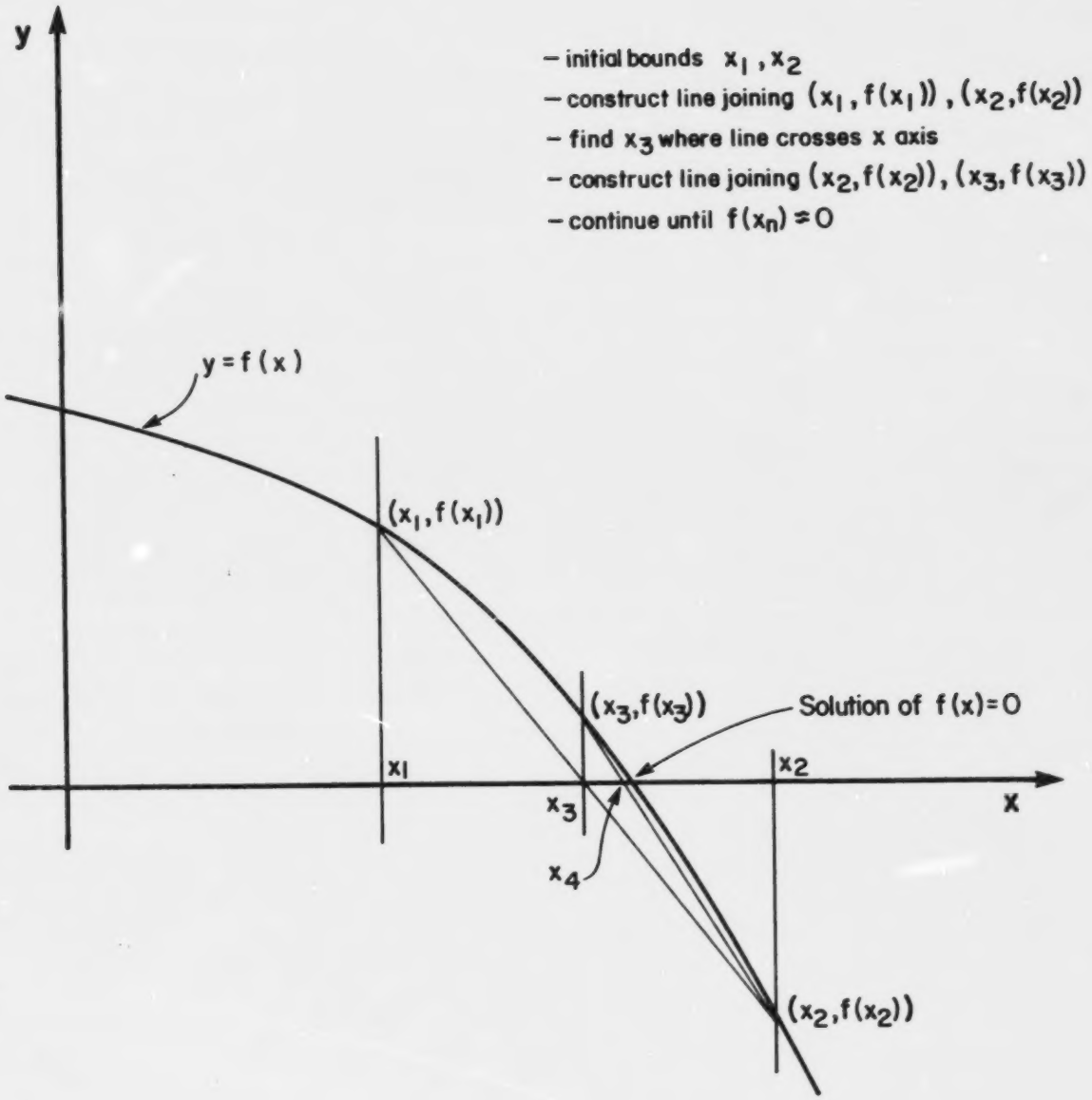


Figure 19 Illustration of Secant Method to Find Solution to $f(x) = 0$ on an Interval

The procedure to find the root is as follows:

1. Using initial bounds of x_1 and x_2, evaluate $f(x_1)$ and $f(x_2)$.

2. If $f(x_1)$ or $f(x_2)$ are greater than zero (or some allowable closing error, such as 10^{-5}) then neither x_1 nor x_2 is the root.

3. Construct a line joining the points $(x_1, f(x_1))$ and $(x_2, f(x_2))$.

4. The value of x where this line crosses the absisca becomes the new estimate of the root. (x_3).

5. If $f(x_3)$ is greater than the closing error, then construct a new line between $(x_3, f(x_3))$ and $(x_2, f(x_2))$ and get a new estimate of x_4 as in step #4.

6. Continue this process until $f(x_n)$ is within the closing error. The value of k_2 is therefore x_n.

Mathematically, the secant method does the following:

1. Choose boundaries x_1, x_2 which are close to, but do not necessarily contain, the root.

2. Evaluate $y_1 = f(x_1)$, $y_2 = f(x_2)$

3. Determine the line joining (x_1, y_1) and (x_2, y_2)

$$y = mx + b$$

$$= \left[\frac{y_2 - y_1}{x_2 - x_1}\right] x + b$$

or $$b = y_1 - \left[\frac{y_2 - y_1}{x_2 - x_1}\right] x_1$$

$$= y_2 - \left[\frac{y_2 - y_1}{x_2 - x_1}\right] x_2$$

4. Determine where that line crosses x axis (i.e. y = 0)

$$f(x_3) = 0 = mx_3 + b$$

$$x_3 = \frac{-b}{m} = \frac{-y_1 + \left[\frac{y_2 - y_1}{x_2 - x_1}\right] x_1}{\left[\frac{y_2 - y_1}{x_2 - x_1}\right]}$$

$$x_3 = \frac{x_1 y_2 - y_1 x_2}{y_2 - y_1}$$

5. Substitute x_2 for x_1, x_3 for x_2, and repeat process n times until $f(x_n) \approx 0$.

Instructions for use on the Apple IIe

(Note: Although these instructions assume an Apple IIe with disk drive, 80-column text card, Kensington System Saver, and printer are available, the program will work on any Apple II with 40 or 80 columns. Slight modifications in the startup procedure are necessary for users with different hardware).

1. Ensure that the red 'in use' indicator light on the disk drive is not lit. Open the disk drive door and check that the drive is empty. Gently insert the disk labeled "Reaeration coefficients", face up, without bending or forcing it. (If you plan to store new dissolved gas data on disk, ensure the disk has no write-protect tab on it). Take care not to touch the shiny surface of the disk itself; handle only the protective covering. Close the drive door. Turn on the computer using the red master switch on the System Saver line-surge suppressor.

2. After a few moments, a menu will appear on the screen listing the program choices available. These include:

    1. Dissolved Gas Data Entry
    2. Reaeration Coefficients (K_2)
    3. Program Descriptions
    4. Exit to BASIC

    (The third item, Program Descriptions, presents brief explanations of first two programs. You may run this program now if you wish).

    If you have not yet entered any dissolved gas data, it is recommended that you use the Dissolved Gas Data Entry program. This routine stores the gas data in a file on the data disk, allowing you to access the information later or re-run the K_2 program without re-typing all of the data. The gas data will be stored in a file with a name of your choice. A listing of the files already on the data disk will be displayed so you don't

inadvertently specify a file which already exists. If you do use a file name which already exists, then the new data will be added to that already in the file. This presents no problem if the new gas data have sample numbers different from the original sample numbers. If, however, any of the new sample numbers correspond to existing numbers, then the old sample data will be erased and replaced with the new data. For example, if the old file contains samples numbered from 1 to 20, and you enter new data numbered 15 to 30, then the old samples numbered 15-20 will be deleted in favour of the new data. If you are unsure which samples already exist in a file, it is best to store the new data in a file of a different name. You might also use file names which describe the contents, such as "Nechako 1985 1-20".

If you append such a file with new data, you may change the name of the file later on using the "RENAME <old file>, <new file>" command (consult DOS manual).

If a data file already exists or if you do not wish to store any data on diskette, then press choice "2" when presented with the program menu. This loads the Reaeration Coefficient program into memory.

3. After a few moments the following message will be displayed on the screen:

"REAERATION COEFFICIENT DETERMINATION.
SYSTEM IDENTIFICATION IN PROGRESS..."

This portion of the program determines the specific Apple system you are using and controls the display accordingly. If there is an 80-column text card available, the program will turn it on and the subsequent screen display will appear compressed. This is to maximize the amount of information which can be displayed on the screen.

4. The next prompt which will appear will be:

"DO YOU WANT A PRINTOUT OF THE RESULTS? PRESS 'Y' FOR YES AND 'N' FOR NO".

If you answer 'Y' then the results will be sent to the printer. If you answer 'N', the results will be displayed on the screen. Since the printer has the capacity for more than 80 columns across, more information will be displayed on the printout than on the screen. Similarly, more information is available on a 80-column screen than on the standard 40-column.

Note that to answer this prompt it was not necessary to press <return>. In some instances where a single-character answer is required, <return> will not be necessary. In these cases, the prompts will say "PRESS" the key. Answers requiring you to press <return> are prompted for with "ENTER".

If you decide you would like a printout, the screen will display a message asking you to ensure that the printer is ready to receive results. It must be both 'ready' and 'on line' as indicated by the LED lights on the printer. Normally, the printer will be ready and on line when you turn on the Master Switch. If it is not, ensure that the printer is turned on and press the button marked 'on line' once or twice until the indicator lamps are lit. If it still will not come on line, consult the printer owner's manual.

If you cannot make the printer operational but still wish to run the program, (i.e. to see the results printed on the screen) then restart the program as follows:

Simultaneously press the <control> and <open apple> (the latter key is located immediately to the left of the space bar on the Apple IIe) keys and hold them down. Press the <reset> key, then release all three keys. This will "re-boot" the disk and restart the procedure from step 2. Continue as described above, except answer "N" to the prompt "DO YOU WANT A PRINTOUT?".

5. The next prompt which will appear is:

"WHICH UNITS OF DISCHARGE DO YOU PREFER?"
"PRESS 1 FOR CFS, 2 FOR CUMECS"

If you press '1' (note, no <return> required) then the discharge you enter and the printout of flow will be in CFS (cubic feet per second, or ft^3s^{-1}). If you press '2' you must enter the discharge in CUMECS (cubic metres per second, or m^3s^{-1}). If you press any other key (by mistake) then the program will re-prompt you for an appropriate answer (i.e. 1 or 2). For this and subsequent numerical entries you may prefer to use the small calculator-style number pad attached to the computer.

6. The program will now ask whether you wish to enter the data via the keyboard or use an existing data file (created by the DISSOLVED GAS program). If you specify a disk file, a listing of the files on the data disk will appear followed by the prompt, "Type the file name you wish to use and press <return>". (N.B. if this prompt does not appear, press the space bar once or twice until it does.) Type the file name and press <return>. If you enter data via the keyboard, it will not be stored and each sample you enter will be erased from memory when the K_2 calculations are completed.

7. If you asked for a printout, a message will now appear on the screen instructing to enter a "descriptive title" for the output. This title is not necessary but is printed for your convenience in identifying the output later on. Your title may include any of characters on the keyboard EXCEPT the comma, or colon (:). If you use one of these characters, anything typed subsequent to that will be ignored and will not appear in the title. You should also avoid using the <ESC> or <CONTROL> keys at this time. Please limit your response to less than 140 characters (approx. 1 1/2 screen widths with the 80 column card) including spaces. If you simply press <RETURN> without typing anything else, no title will be displayed.

8. At this point the printer is ready to display the column headings (if you asked for a printout). The screen will display a message telling you to expect the printer to begin once you press any key. During the time the headings are printed, the screen will remain blank. When printing is completed control will return to the screen and the next prompt will appear. If you did not wish for a printout, steps 7 and 8 will not be performed and the program proceeds to step 9.

9. "ENTER THE DISCHARGE IN XX UNITS"

   Where "XX" is either CFS or CUMECS depending on your answer in step 4. Type the discharge observed in the river at the time of sampling, including if applicable a decimal point, then press <return>. A decimal is not required if the discharge is a 'round' number, eg. 121.0 cumecs can be entered simply as 121 <return>. If you make a mistake, use the arrow keys to correct it before pressing return. If you pressed <return> before you realized you made a mistake, you will have the opportunity to correct the error later in the program. The actual value of discharge is not used in the calculations, but recent evidence suggests that K_2 has a flow-dependent relationship (Byres and Servizi 1986) which should be considered when using values of K_2 in future work. The output therefore displays the discharge beside the value of K_2 to avoid any ambiguities.

10. "ENTER THE REACH NUMBER FOR THI3 DATA PAIR"

Typically a long river is broken up into sub sections or reaches for the purpose of evaluating K_2. Values of K_2 are dependent on channel morphology and thus vary as the river changes its characteristics. The upstream and downstream samples are taken at the boundaries of the reach used, and the reaches themselves are assigned arbitrary numbers. Type the number of the reach you are working on and press <return>. (N.B. - Reaches should be assigned to the river in such a manner that major tributaries, if any, are excluded. If a reach has a tributary immediately upstream, ensure that the upstream sample is taken in "well mixed" water, or apply a flow-weighted mixing calculation).

11. "ENTER THE UPSTREAM SAMPLE NUMBER"

This is the number arbitrarily assigned to the sample taken at the upstream boundary of the reach. The samples are numbered to differentiate between several pairs of samples which may have been taken for that reach. Type the number and press <return>.

12. The next series of prompts asks you for the dissolved gas data for stations at each end of the reach in the following order:

Water Temperature	(°C)
Dissolved Oxygen	(mgL^{-1})
Barometric Pressure	(mmHg)
Tensionometer Reading	(mmHg)

The entered values must all be in the units asked for, or erroneous answers will result. In each case type the number including decimal values (if applicable) and press <return>.

7. If you asked for a printout, a message will now appear on the screen instructing to enter a "descriptive title" for the output. This title is not necessary but is printed for your convenience in identifying the output later on. Your title may include any of characters on the keyboard EXCEPT the comma, or colon (:). If you use one of these characters, anything typed subsequent to that will be ignored and will not appear in the title. You should also avoid using the <ESC> or <CONTROL> keys at this time. Please limit your response to less than 140 characters (approx. 1 1/2 screen widths with the 80 column card) including spaces. If you simply press <RETURN> without typing anything else, no title will be displayed.

8. At this point the printer is ready to display the column headings (if you asked for a printout). The screen will display a message telling you to expect the printer to begin once you press any key. During the time the headings are printed, the screen will remain blank. When printing is completed control will return to the screen and the next prompt will appear. If you did not wish for a printout, steps 7 and 8 will not be performed and the program proceeds to step 9.

9. "ENTER THE DISCHARGE IN XX UNITS"

   Where "XX" is either CFS or CUMECS depending on your answer in step 4. Type the discharge observed in the river at the time of sampling, including if applicable a decimal point, then press <return>. A decimal is not required if the discharge is a 'round' number, eg. 121.0 cumecs can be entered simply as 121 <return>. If you make a mistake, use the arrow keys to correct it before pressing return. If you pressed <return> before you realized you made a mistake, you will have the opportunity to correct the error later in the program. The actual value of discharge is not used in the calculations, but recent evidence suggests that K_2 has a flow-dependent relationship (Byres and Servizi 1986) which should be considered when using values of K_2 in future work. The output therefore displays the discharge beside the value of K_2 to avoid any ambiguities.

10. "ENTER THE REACH NUMBER FOR THIS DATA PAIR"

Typically a long river is broken up into sub sections or reaches for the purpose of evaluating K_2. Values of K_2 are dependent on channel morphology and thus vary as the river changes its characteristics. The upstream and downstream samples are taken at the boundaries of the reach used, and the reaches themselves are assigned arbitrary numbers. Type the number of the reach you are working on and press <return>. (N.B. - Reaches should be assigned to the river in such a manner that major tributaries, if any, are excluded. If a reach has a tributary immediately upstream, ensure that the upstream sample is taken in "well mixed" water, or apply a flow-weighted mixing calculation).

11. "ENTER THE UPSTREAM SAMPLE NUMBER"

This is the number arbitrarily assigned to the sample taken at the upstream boundary of the reach. The samples are numbered to differentiate between several pairs of samples which may have been taken for that reach. Type the number and press <return>.

12. The next series of prompts asks you for the dissolved gas data for stations at each end of the reach in the following order:

Water Temperature	(°C)
Dissolved Oxygen	(mgL^{-1})
Barometric Pressure	(mmHg)
Tensionometer Reading	(mmHg)

The entered values must all be in the units asked for, or erroneous answers will result. In each case type the number including decimal values (if applicable) and press <return>.

13. If you made a mistake in entering any of the values so far, you now have the opportunity to make corrections. The screen will display the values you entered, as well as the prompt, "DO YOU WISH TO MAKE ANY CHANGES? (Y/N)". Press 'Y' for yes or 'N' for no. If you answered yes, the screen will prompt you to press the number on the screen proceeding each of the entered values, then ask you for the correct value. Type the new value and press <return>. This process will be repeated until you are satisfied with the values entered.

14. When you answer 'no' to the prompt from step 13, the program will store those values, then ask you to begin entering the data for the downstream sample. The procedure is identical to that described in steps 11-13. Just answer the prompts by typing the applicable data and pressing <return>.

15. "ENTER THE FLOW TRAVEL TIME (IN HOURS)".

    The value of time used should be input in decimal hours. Use a decimal point to separate the whole and fractional portions. If for example you have recorded the travel time or the data sheets as 8 hours, 25 minutes (8:25), convert this to the decimal form of 8 + 25/60 = 8.42 hours.

    Travel times must be obtained from whatever information is available, such as flow routing models, dye tests, or the compilation of velocity-discharge relations over the river reach. Since the value of travel time not only appears in the Streeter-Phelps equation but determines sampling times and hence dissolved gas levels, care should be taken to use as accurate a travel time as possible. Type the value of travel time and press <return>.

16. Data entry for this sample pair is now complete. The program will require several seconds to perform the calculations before displaying the results. If you asked for a printout, the printer will display both the input data and the calculated values. Calculated values displayed are % total gas pressure (TGP), dissolved and saturation concentrations of the "combined gas" nitrogen and argon (N_2 + Ar), and the value of K_2 for the reach. The value of K_2 has been converted to what it would be at 20°C, and is to the natural logarithmic base of "e". Values can be converted, if desired, to base 10 as follows:

$$k_2(\text{base 10}) = K_2(\text{base e}) \ (0.4342945)$$

If you did not ask for a printout and your computer has an 80 column text card, you will see the same results except for the raw data and the value of % TGP, which were omitted for lack of screen space. If you did not ask for a printout and do not have an 80 column card you will only see the Reach number, Discharge, %TGP of the samples, and the value of $K_2(20)e$.

17. After the results are displayed, the prompt "DO YOU WISH TO CONTINUE? (Y/N)" will appear on the screen. Press 'Y' if you have more data and would like to continue calculating values of K_2. If you press 'N' the program will end and return to the program menu in step 2.

If you wish to run another program, type the appropriate menu number and press <return>. Otherwise, choose option 4 (Exit) and you will be left in "immediate mode" with the "]" prompt character at the lower left corner of the screen.

18. If for some reason you wish to discontinue the program before its completion, you may do so in the following ways:

    a) When the calculations are in progress or when the computer prompts you to ENTER the value, the program may be halted by pressing <CONTOL-C>. (Press and hold down the <CTRL> or <CONTROL> key and press "C" before releasing both keys simultaneously). If nothing happens press <return>. Note that this will not work if the computer is prompting for a single character input with the word "PRESS". In this case answer the Y/N or other PRESS prompts until "ENTER" prompt occurs, then try the <CTRL-C> <return> method.

    b) Another method which will work is to press the <CONTROL> and <RESET> keys simultaneously. If this does not work, try pressing the <ESC>, <open-apple>, and <RESET> keys simultaneously. This will restart the program from step 2. Press 4 <return> to end the program.

    c) As a last resort to get out of the program you can remove the disk from the drive (once the in-use lamp goes out) and turn off the computer with the red master switch.

19. Remove the printout (if any) from the printer by carefully advancing the paper with the roller knob until the last line of output is past the clear plastic printer cover. Holding the cover in place with one hand, lift the output straight up, starting at one side of the page and tearing across to the other. Alternatively, continue to advance the paper until the next perforation between sheets is past the tractor wheels, and separate at the perforation.

Interpreting the Results

Figure 20 shows one page of sample output after running this program.

Data to the left of the vertical line (between "Tensionometer Reading" and "% TGP") are the field data as entered by the user. Data to the right of the line (with the exception of "Travel Time", "Discharge", and "Reach") are calculated values based on the input data. The value of K_2 at the extreme right is to the logarithmic base "e" and has been converted to 20°C.

In some cases, a diagnostic message may appear under the columns labeled "travel time" to "K_2" inclusive. The types of messages displayed may be: "UNDERSAT, U/S SAMPLE", "UNDERSAT, D/S SAMPLE", or "TEMP. CHANGE TOO LARGE". Should one of these appear, then the data as entered are not amenable to calculating K_2. Reaeration is assumed to cause the gas content in the stream to decrease asymptotically to the 100 % saturation level. If either of the samples is undersaturated, (% TGP less than 100%) then some factor other than reaeration has influenced the gas levels. This may also be the case if either of the samples is greater than, but very close to, 100%. It is recommended that values of % TGP be greater than 103-104 % for best results.

If the temperature change is large between samples, then the value of the solubility concentration changes significantly. This effect can sometimes exceed the ability of the temperature-correcting algorithm to adjust the saturation levels, and cause samples to appear undersaturated when a calculation of K_2 is attempted. The message "TEMP. CHANGE TOO LARGE" is an indication of this. For cases where % TGP levels are in the order of 105-110%, this condition will rarely be a problem.

In rare cases the program may produce a negative value of K_2. This indicates that the gas content had actually <u>increased</u> downstream, even after the temperature effects had been accounted for. In such a case the value of K_2 is NOT reasonable, i.e. some effect other than reaeration has influenced gas levels (such as a major tributary, etc.).

FIG. 20

REAERATION (K2) COEFFICIENT DETERMINATION

NECHAKO RIVER JULY/AUG 1985

Sample #	Water Temp C	Dissolved Oxygen mg/l	Barometric Pressure mmHg	Tensionometer Reading mmHg	TGP moist air	Dissolved N2+Ar mg/l	Sat.Conc. N2+Ar mg/l	Travel Time hours	Discharge CUMECS	Reach #	K2(20) base e per hr
2	12.4	10.25	702.8	48	106.8	17.81	16.53				
6	14.4	10.4	705.7	48	106.8	16.91	15.93	5.5	62.3	1	.1377
3	13.3	10.5	703	47	106.7	17.26	16.23				
7	14.5	10.25	706	50	107.1	17	15.9	5.5	62.3	1	.0434
112	16.2	10.4	705.4	105	114.9	17.74	15.36				
115	16.8	10.35	705.8	95	113.5	17.23	15.19	3.9	289	1	.0619
113	16.2	10.35	705.6	106	115	17.8	15.37				
116	16.6	10.3	705.8	93	113.2	17.28	15.25	3.9	289	1	.0626
10	11	10.4	709.7	26	103.7	17.96	17.19				
12	14.7	10.2	707.2	54	107.6	17.09	15.87	7.75	62.3	2	.0823
11	11.6	10.45	709.9	38	105.4	18.02	16.98				
13	15	10.2	707.2	56	107.9	17.01	15.77	7.75	62.3	2	.0897
106	17.6	9.75	698.1	80	111.5	16.54	14.8				
109	16.6	8.8	702.9	18	102.6	15.78	15.19	14.8	289	3	.0597
31	16	9.5	699.2	37	105.3	16.14	15.29				
34	15.5	9.15	706.5	6	100.8	15.82	15.6	18.2	138	4	.0535

```
]LIST

100  REM      *** K2 COEFFICIENT DETERMINATION ***
110  REM      ***    V3      DECEMBER 1985       ***
120  REM      ***           RON BYRES            ***
130  REM
140  REM     WRITTEN FOR APPLE IIe WITH 80
150  REM          COLUMN TEXT CARD
160  REM     (SHOULD ALSO WORK ON ANY APPLE II
170  REM     WITH OR WITHOUT 80 COLUMN CARD )

180  ONERR  GOTO 2880: REM   PREVENT CRASH DUE TO UNANTICIPATED ERROR
190  HOME : TEXT : VTAB 10
200  PRINT "REAERATION  COEFFICIENT DETERMINATION"
210  PRINT : PRINT " SYSTEM IDENTIFICATION IN PROGRESS..."
220 D$ = "": REM  THERE IS AN INVISIBLE 'CTRL D' IN THE QUOTES
230  GOSUB 3320: IF RESULT >  = 64 THEN COL80 = 1.0: PRINT D$;"PR#3": REM
         USE 80 COLUMN CARD IF AVAILABLE
240  HOME : VTAB 5
250  PRINT "   REAERATION (K2) COEFFICIENT DETERMINATION "
260  PRINT " ": PRINT " "
270  PRINT "DO YOU WANT A PRINTOUT OF THE RESULTS ?"
280  PRINT "PRESS 'Y' FOR YES OR 'N' FOR NO": PRINT " "
290  GET PR$
300  IF PR$ <  > "Y" AND PR$ <  > "N" GOTO 280
310  IF PR$ = "N" THEN PR = 0.0: GOTO 400
320 PR = 1.0:AN$ = "Please ensure that the printer is turned on and that
     both the 'on line' and 'ready' indicator lamps are lit. Also, if you
      wish to avoid having the output printed on top of the perforation b
     etween two sheets, use the "
330  GOSUB 3050: REM  SCREEN FORMATTER ROUTINE
340 AN$ = "paper advance knob ( located on right-hand side of printer) to
      advance the paper until the next perforation is positioned about 1
     inch above the top of the printer ribbon."
350  GOSUB 3050: REM  SCREEN FORMATTER
360  PRINT : PRINT : PRINT "PRESS ANY KEY TO CONTINUE": GET A$
370  PRINT "THANK YOU": PRINT " ":HEADER = 0.0
380  REM

390  PRINT : PRINT : PRINT
400  PRINT "WHICH UNITS OF DISCHARGE DO YOU PREFER ?"
410  PRINT "PRESS '1' FOR CFS, OR '2' FOR CUMECS": GET U$
420  IF U$ <  > "1" AND U$ <  > "2" GOTO 410
430 UNIT$ = "CUMECS": IF U$ = "1" THEN UNIT$ = "CFS"
440  IF  NOT PR GOTO 560
450  HOME : VTAB 5
460 AN$ = "You may now enter a descriptive title which will be printed ou
     t on the output. This could include, for example, the name of the ri
     ver, the date(s) the samples were collected, your name, or some othe
     r title.": GOSUB 3050
```

```
470 AN$ = "Your title may be any combination of letters and numbers but p
    lease DO NOT use any commas or colons (Semi-colons (;) are acceptabl
    e). Also, your response should be limited to less than 140 character
    s.": GOSUB 3050
480 AN$ = "For example, a typical entry might be ' NECHAKO RIVER  JUL-AUG
      /1985 . ENTERED BY R.C.'.": GOSUB 3050
490 AN$ = "Type the title you wish and press <RETURN>  (or simply press <
    RETURN> for none).": GOSUB 3050
500  PRINT : PRINT : PRINT : INPUT " ";TITLE$
510  HOME : VTAB 5
520 AN$ = "The printer will now display the column headings for the outpu
    t. When printing is completed, control will return to the screen. Pr
    ess any key to continue..."
530  GOSUB 3050
540  GET A$: GOSUB 2180
550  REM

560  HOME : VTAB 5
570 AN$ = "Do you wish to enter the data from the keyboard, or is there a
    n EXISTING data file on diskette you wish to use? (Press 'K' for key
    board entry or 'D' for disk file) ": GOSUB 3050
580  GET ENTRY$
590  IF ENTRY$ <  > "K" AND ENTRY$ <  > "D" GOTO 580
600  IF ENTRY$ = "K" GOTO 660
610  PRINT : PRINT : PRINT "THIS DISK CONTAINS THE FOLLOWING FILES:"
620  PRINT D$;"CATALOG": PRINT : PRINT
630  PRINT "ENTER THE NAME OF THE DATA FILE YOU WISH TO USE:"
640  INPUT " ";N$:NL$ = N$ + ",L50"
650  REM

660  REM     FUNCTIONS TO PRODUCE OUTPUT TO 1,2,& 4 DECIMAL PLACES
670  DEF  FN R1(X) =  INT (10 * X + 0.5) / 10
680  DEF  FN R2(X) =  INT (100 * X + 0.5) / 100
690  DEF  FN R4(X) =  INT (10000 * X + 0.5) / 10000
700  REM

710  HOME : VTAB 5
720  INPUT "ENTER THE REACH NUMBER FOR THE DATA YOU WISH TO USE ";R
730  INPUT "ENTER THE NUMBER ASSIGNED TO THE UPSTREAM SAMPLE ";NO
740 S$ = "UPSTREAM":N = NO
750  PRINT : PRINT "ENTER THE DISCHARGE, IN ";UNIT$;
760  INPUT "   ";Q
770  IF ENTRY$ = "D" THEN  GOSUB 3540
780  GOSUB 1220: REM  GET TEMP,BP,DO,DP,AND CALC. SO,CO
790 TO = T:CO = C:SO = CS:MO = MTGP: REM   GAS RESULTS = U/S SAMPLE
800 BO = BP:OO = DO:USTEN = DP:MUTGP = MTGP
810  HOME
820  HOME : VTAB 5
```

```
830  REM

840  INPUT "ENTER THE NUMBER ASSIGNED TO THE DOWNSTREAM SAMPLE ";N1
850 S$ = "DOWNSTREAM":N = N1
860  IF ENTRY$ = "D" THEN  GOSUB 3540
870  GOSUB 1220: REM  GET TEMP,BP,DO,DP,AND CALC. SO,CO
880 T1 = T:C1 = C:S1 = CS:M1 = MTGP: REM  GAS RESULTS = D/S SAMPLE
890 B1 = BP:O1 = DO:DSTEN = DP:MDTGP = MTGP
900  HOME : VTAB 5
910  INPUT "ENTER THE FLOW TRAVEL TIME (IN HOURS) ";TIME
920  IF Q$ = "Y" THEN  GOTO 930
930  HOME : VTAB 5
940  PRINT " ": PRINT "CALCULATIONS IN PROGRESS, PLEASE WAIT..."
950  GOSUB 1920: REM   SECANT ALGORITHM FOR K2
960  IF PR THEN  GOSUB 2430: GOTO 1120: REM  PRINT GAS DATA AND K2 RESULT
     S
970  REM   SEND OUTPUT TO 80 COL SCREEN :
980  IF COL80 THEN  GOSUB 2640: GOTO 1120
990  REM   SEND OUTPUT TO 40 COL SCREEN
1000  HOME : VTAB 5
1010  PRINT "REACH #           ";R
1020  PRINT "DISCHARGE        ";Q;" ";UNIT$
1030  PRINT "UPSTREAM   TGP    "; FN R1(MUTGP);" %"
1040  PRINT "DOWNSTREAM TGP    "; FN R1(MDTGP);" %"
1050  PRINT : PRINT
1060  PRINT "DATA PAIR (";NO;",";N1;")";: POKE 36,22
1070  IF GC THEN  IF MD > 100 AND MU > 100 THEN  PRINT "TEMP CHANGE": HTAB
     22:"TOO LARGE": GOTO 1120
1080  IF DIV THEN  PRINT " NO CONVERGENCE AFTER": POKE 36,23: PRINT "25 P
     ASSES": GOTO 1120
1090  IF GCRASH THEN  PRINT " UNDERSAT. SAMPLE": POKE 36,23: PRINT "K2 UN
     DEFINED": GOTO 1120
1100  PRINT "K2(20)e = ";: PRINT  FN R4(KTE)
1110  REM

1120  PRINT : PRINT
1130  PRINT "DO YOU WISH TO CONTINUE? (Y/N)"
1140  GET A$
1150  IF A$ <  > "Y" AND A$ <  > "N" THEN  PRINT "PLEASE PRESS 'Y' OR 'N'
     ": GOTO 1140
1160  IF A$ = "Y" GOTO 660
1180  REM  END THE PROGRAM AND LEAVE USER IN 40 COL MODE, CHECKER BOARD C
     URSOR
1190  POKE 216,0: REM  RESTORE NORMAL ERROR FUNCTIONS TO COMPUTER
1200  PRINT : PRINT  CHR$ (4);"RUN STARTUP"
1210  REM  RETURN TO MENU


1220  REM  =====<SUBROUTINE TO GET GAS DATA AND DO PRELIM CALCS>=====
1230  IF ENTRY$ = "D" GOTO 1620
1240  INPUT "WATER TEMPERATURE     = ? (celcius) ";T
1250  INPUT "DISSOLVED OXYGEN      = ? (mg/l)    ";DO
1260  INPUT "BAROMETRIC PRESSURE   = ? (mmHg)    ";BP
```

```
1270  INPUT "TENSIONOMETER READING = ? (mmHg)     ";DP
1280  REM

1290  REM  CHECK THE VALUES ENTERED
1300  HOME : VTAB 5
1310  PRINT "THE VALUES YOU ENTERED ARE AS FOLLOWS:": PRINT " "
1320  PRINT "1. ";"DISCHARGE     ";: HTAB 30: PRINT Q;" ";UNIT$
1330  PRINT "2. ";"REACH NUMBER ";: HTAB 30: PRINT R
1340  PRINT "3. ";S$;" SAMPLE NUMBER ";: HTAB 30: PRINT N
1350  PRINT "4. ";"TEMPERATURE ";: HTAB 30: PRINT T;" C"
1360  PRINT "5. ";"DISSOLVED OXYGEN ";: HTAB 30: PRINT DO;" mg/l"
1370  PRINT "6. ";"BAROMETRIC PRESSURE ";: HTAB 30: PRINT BP;" mmHg"
1380  PRINT "7. ";"TENSIONOMETER dP ";: HTAB 30: PRINT DP;" mmHg"
1390  PRINT " "
1400  REM

1410  PRINT "DO YOU WANT TO MAKE ANY CHANGES ? (Y/N)"
1420  GET A$
1430  IF A$ <  > "Y" AND A$ <  > "N" THEN  PRINT "PLEASE PRESS 'Y' OR 'N'
     ": GOTO 1420
1440  IF A$ = "N" GOTO 1590
1450  PRINT " ": PRINT "PRESS THE NUMBER PRECEEDING THE VALUE YOU WISH TO
      CHANGE"
1460  PRINT "(Eg. If you wish to change 'Temperature', press '4' )
1470  GET CH$:CH =  VAL (CH$): IF CH < 1 OR CH > 7 THEN  PRINT "Please pr
     ess a number between 1 and 7": GOTO 1470
1480  PRINT " "
1490  INPUT "ENTER THE NEW VALUE ";FIX
1500  ON CH GOTO 1510,1520,1530,1540,1550,1560,1570
1510 Q = FIX: GOTO 1580
1520 R = FIX: GOTO 1580
1530 N = FIX: GOTO 1580
1540 T = FIX: GOTO 1580
1550 DO = FIX: GOTO 1580
1560 BP = FIX: GOTO 1580
1570 DP = FIX: GOTO 1580
1580  HOME : VTAB 5: PRINT "THE VALUES ARE NOW AS FOLLOWS:": PRINT " ": GOTO
     1320

1590  REM
1600  REM   CALCULATE TGP AND SATURATION VALUES
1610  REM  WATER VAPOUR PRESSURE
1620 WVP = ( EXP (52.418 - 6788.6 / (T + 273.15) - 5.0016 *  LOG (T + 273
     .15))) * 760 / 101.325
1630  REM  TGP MOIST AND DRY
1640 MTGP = (BP + DP) * 100 / BP
1650 DTGP = (BP + DP - WVP) * 100 / BP
1660  REM  BUNSEN COEF FOR O2
1670 TA = T + 273.15
1680 BO2 =  EXP (85.8079 * 100 / TA + 23.8439 *  LOG (TA / 100) - 58.3877
     )
1690  REM  PARTIAL PRESSURES AND %SATURATION
1700  REM  X = COMBINED N2+AR GAS,N=N2,A=AR,P=PARTIAL PRESSURE
```

```
1710 PO2 = DO * 0.5318 / BO2
1720 PX = BP + DP - WVP - PO2
1730 XPRCNT = 100 * PX / (BP - WVP) * 0.79018
1740 O2PRCNT = PO2 * 100 / (BP - WVP) * 0.2095
1750  REM  CALC BUNSEN COEF FOR N2+AR
1760 BN =  EXP (85.7661 * 100 / TA + 24.3696 *  LOG (TA / 100) - 59.6274)

1770 BA =  EXP (82.0262 * 100 / TA + 22.5929 *  LOG (TA / 100) - 55.6578)

1780 B1 = BN * 0.78084 + BA * 0.00934
1790 BX = B1 / 0.79018
1800  REM  CALC 'A' FACTOR FOR N2+AR
1810 AX = 0.76 * B1 / (0.97639 * BN + 0.01666 * BA)
1820  REM  CONCENTRATIONS AND SOLUBILITIES FOR N2+AR
1830 C = PX * BX / AX
1840 ZN = 248.4262 * 100 / TA + 143.0738 *  LOG (TA / 100) - 21.712 * TA /
     100 - 172.4965
1850 CN = 1.25043 *  EXP (ZN): REM  SOLUBILITY OF N2
1860 ZA = 245.451 * 100 / TA + 141.8222 *  LOG (TA / 100) - 21.802 * TA /
     100 - 173.5146
1870 CA = 1.78419 *  EXP (ZA): REM  SOLUBILITY OF ARGON
1880 C760 = CN + CA: REM  SOLUBILITY N2+AR AT 760 mmHg
1890 CS = C760 * (BP - WVP) / (760 - WVP): REM  SOL N2+AR AT LOCAL BP
1900  RETURN
1910  REM


1920  REM  =====<SUBROUTINE TO CALC K2 (SECANT METHOD) >=====
1930 ITER = 0.0:DIV = 0.0:EPS = 0.00001:GCRASH = 0.0
1940 X1 = 0.01:X2 = 0.1: REM  INITIAL BOUNDS OF K2 ESTIMATE
1950 K0 = X1: REM  USE INITIAL BOUNDS OF K2 TO GET NEW ESTIMATE (X3)
1960  GOSUB 2100
1970 Y1 = ERR
1980 K0 = X2: GOSUB 2100
1990 Y2 = ERR
2000  IF Y1 = Y2 THEN X3 = (X1 + X2) / 2: GOTO 2020: REM  PREVENT CRASH I
     F Y1=Y2 (UNLIKELY)
2010 X3 = (Y1 * X2 - Y2 * X1) / (Y1 - Y2)
2020 K0 = X3: GOSUB 2100
2030  IF  ABS (ERR) < EPS GOTO 2070
2040 ITER = ITER + 1: IF ITER > 25 THEN DIV = 1.0: GOTO 2070: REM   NO CO
     NVERGENCE
2050 X1 = X2:X2 = X3: REM  RESET BOUNDS AND TRY AGAIN
2060  GOTO 1950

2070 K2E = X3 / 0.434294: REM  CONVERT FROM BASE 10 TO BASE e
2080 KTE = K2E / 1.024 ^ ((T0 + T1) / 2 - 20): REM   CONVERT TO 20 DEGREE
     S C
2090  RETURN
2100  REM  K2 ALGORITHM
2110 D = (S0 - S1) * (1 - 10 ^ ( - K0 * TIME))
2120 G = (100 * (C1 + D) / S0 - 100) / (100 * C0 / S0 - 100)
2130  IF G <  = 0.0 THEN GCRASH = 1: GOTO 2160
```

```
2140  REM  PREVENT CRASH FROM UNDERSAT. SAMPLE ( G NOT POSITIVE)
2150 ERR =  - 0.434294 *  LOG (G) / TIME - KO: REM  DIFF BETWEEN CALC'D &
     EST'D K2
2160  RETURN
2170  REM


2180  REM  ====< PRINTOUT COLUMN HEADERS (140 COL HARDWARE) >====
2190  PRINT  CHR$ (12): PRINT D$;"PR#1": REM  CLR SCREEN,OPEN PRINTER FIL
     E
2200  PRINT  CHR$ (27)"N" CHR$ (12): REM  SKIP OVER PERFORATION
2210  PRINT  CHR$ (9)"140N": PRINT  CHR$ (15): REM  PRINT WIDTH 140 COL,1
     5 CPI
2220  PRINT "REAERATION (K2) COEFFICIENT DETERMINATION ": PRINT
2230  PRINT TITLE$: PRINT
2240  FOR I = 1 TO 133: PRINT "=";: NEXT : PRINT ""
2250  PRINT "Sample";: POKE 36,9: PRINT "Water";: POKE 36,18: PRINT "Diss
     olved";: POKE 36,30: PRINT "Barometric";: POKE 36,42: PRINT "Tension
     ometer";: POKE 36,58: PRINT "|";
2260  POKE 36,60: PRINT "%TGP";
2270  POKE 36,68: PRINT "Dissolved";: POKE 36,79: PRINT "Sat.Conc.";
2280  POKE 36,93: PRINT "Travel";: POKE 36,103: PRINT "Discharge";: POKE
     36,116: PRINT "Reach";
2290  POKE 36,125: PRINT "K2(20)"
2300  PRINT "  #";: POKE 36,9: PRINT "Temp";: POKE 36,19: PRINT "Oxygen";
     : POKE 36,31: PRINT "Pressure";: POKE 36,44: PRINT "Reading";: POKE
     36,58: PRINT "|";
2310  POKE 36,60: PRINT "moist";
2320  POKE 36,69: PRINT "N2+Ar";: POKE 36,80: PRINT "N2+Ar";: POKE 36,94:
      PRINT "Time";
2330  POKE 36,118: PRINT "#";: POKE 36,125: PRINT "base e"
2340  POKE 36,11: PRINT "C";: POKE 36,20: PRINT "mg/l";: POKE 36,33: PRINT
     "mmHg";: POKE 36,44: PRINT "mmHg";: POKE 36,58: PRINT "|";
2350  POKE 36,60: PRINT " air";
2360  POKE 36,69: PRINT "mg/l";: POKE 36,80: PRINT "mg/l";: POKE 36,94: PRINT
     "hours";
2370  POKE 36,105: PRINT UNIT$;: POKE 36,125: PRINT "per hr"
2380  FOR I = 1 TO 133: PRINT "=";: NEXT : PRINT " "
2390  IF COL80 THEN  PRINT D$;"PR#3": GOTO 2410
2400  PRINT D$;"PR#0"
2410  RETURN
2420  REM


2430  REM     ====< SEND U/S DATA TO PRINTER >====
2440  PRINT  CHR$ (21)
2450  PRINT D$;"PR#1"
2460  POKE 36,2: PRINT NO;: POKE 36,10: PRINT TO;: POKE 36,20: PRINT OO;:
      POKE 36,33: PRINT BO;: POKE 36,46: PRINT USTEN;: POKE 36,58: PRINT
     "|";
2470  POKE 36,60: PRINT  FN R1(MUTGP);
2480  POKE 36,69: PRINT  FN R2(CO);: POKE 36,80: PRINT  FN R2(SO)
2490  REM  ====< PRINTOUT K2 RESULTS >====
```

```
2500  IF SO > CO THEN  POKE 36,58: PRINT "!";: PRINT "  UNDERSAT'D U/S SA
     MPLE": GOTO 2560
2510  IF S1 > C1 THEN  POKE 36,58: PRINT "!";: PRINT "UNDERSAT'D D/S SAMP
     LE": GOTO 2560
2520  IF GCRASH THEN  POKE 36,58: PRINT "!";: PRINT "TEMP CHANGE TOO LARG
     E": GOTO 2560
2530  IF DIV THEN  POKE 36,58: PRINT "!";: PRINT "NO CONVERGENCE AFTER 25
      LOOPS": GOTO 2560
2540  POKE 36,58: PRINT "!";: POKE 36,95: PRINT TIME;: POKE 36,105: PRINT
     Q;: POKE 36,118: PRINT R;: POKE 36,125: PRINT  FN R4(KTE)
2550  REM  ====< PRINTOUT D/S GAS DATA >====
2560  POKE 36,2: PRINT N1;: POKE 36,10: PRINT T1;: POKE 36,20: PRINT O1;:
      POKE 36,33: PRINT B1;: POKE 36,46: PRINT DSTEN;: POKE 36,58: PRINT
     "!";
2570  POKE 36,60: PRINT  FN R1(MDTGP);
2580  POKE 36,69: PRINT  FN R2(C1);: POKE 36,80: PRINT  FN R2(S1)
2590  FOR I = 1 TO 133: PRINT "-";: NEXT : PRINT " "
2600  IF COL80 THEN  PRINT D$;"PR#3": GOTO 2620
2610  PRINT D$;"PR#0"
2620  RETURN
2630  REM


2640  REM  ====< SEND PRINTOUT TO 80 COLUMN SCREEN >====
2650  HOME : VTAB 5: FOR I = 1 TO 77: PRINT "=";: NEXT : PRINT ""
2660  PRINT "Sample";: POKE 36,10: PRINT "Dissolved";: POKE 36,24: PRINT
     "Sat.Conc.";: POKE 36,35: PRINT "%TGP";
2670  POKE 36,43: PRINT "Travel";: POKE 36,51: PRINT "Discharge";: POKE 3
     6,62: PRINT "Reach";
2680  POKE 36,70: PRINT "K2(20)"
2690  PRINT "  #";: POKE 36,12: PRINT "N2+Ar";: POKE 36,26: PRINT "N2+Ar"
     ;: POKE 36,35: PRINT "moist";: POKE 36,44: PRINT "Time";
2700  POKE 36,64: PRINT "#";: POKE 36,70: PRINT "base e"
2710  POKE 36,12: PRINT "mg/l";: POKE 36,26: PRINT "mg/l";: POKE 36,35: PRINT
     "air";: POKE 36,43: PRINT "hours";
2720  POKE 36,53: PRINT UNIT$;: POKE 36,70: PRINT "per hr"
2730  FOR I = 1 TO 77: PRINT "=";: NEXT
2740  PRINT " ": PRINT " "
2750  REM  SEND RESULTS TO SCREEN
2760  POKE 36,2: PRINT NO;: POKE 36,12: PRINT  FN R2(CO);: POKE 36,26: PRINT
      FN R2(SO);
2770  POKE 36,35: PRINT  FN R1(MO)
2780  IF DIV THEN  POKE 36,45: PRINT "NO CONVERGENCE AFTER 25 LOOPS": GOTO
     2830
2790  IF CO < SO THEN  POKE 36,45: PRINT "UNDERSAT. U/S SAMPLE": GOTO 283
     0
2800  IF C1 < S1 THEN  POKE 36,45: PRINT "UNDERSAT. D/S SAMPLE": GOTO 283
     0
2810  IF GCRASH THEN  POKE 36,45: PRINT "TEMP. CHANGE TOO LARGE": GOTO 28
     30
2820  POKE 36,45: PRINT TIME;: POKE 36,53: PRINT Q;: POKE 36,64: PRINT R;
     : POKE 36,71: PRINT  FN R4(KTE)
2830  POKE 36,2: PRINT N1;: POKE 36,12: PRINT  FN R2(C1);: POKE 36,26: PRINT
```

```
     FN R2(S1);: POKE 36,35: PRINT  FN R1(M1)
2840  FOR I = 1 TO 77: PRINT "-";: NEXT
2850  PRINT " "
2860  RETURN
2870  REM


2880  REM  ====< ERROR HANDLING ROUTINE >====
2890 EC =  PEEK (222): REM  ERROR CODE
2900 LEC =  PEEK (219) * 256 +  PEEK (218): REM  LINE ERROR OCCURRED
2910  IF EC = 255 THEN  END : REM  255 IS CTRL-C
2920  CALL  - 3288: REM  CLEAR MEMORY STACK BEFORE RESUMING WITH A GOTO
2930  HOME : VTAB 5
2940  PRINT  CHR$ (7): PRINT  CHR$ (7): REM  WARNING BELL
2950  IF EC = 6 THEN  PRINT : PRINT "THE FILE YOU SPECIFIED IS NOT ON THI
     S DISK. CHECK CATALOG LISTING.": PRINT "PRESS ANY KEY TO CONTINUE...
     ": GET A$: GOTO 560
2960  PRINT "      **********": PRINT : PRINT
2970 AN$ = "AN ERROR HAS INTERRUPTED THE PROGRAM AT LINE " +  STR$ (LEC) +
     " .": GOSUB 3050
2980  IF EC = 53 OR EC = 69 OR EC = 133 THEN AN$ = "PROBABLE CAUSE: MISTA
     KE IN DATA ENTRY OR VERY UNUSUAL SAMPLE.  CHECK DATA AND TRY AGAIN O
     R USE NEW DATA.": GOSUB 3050
2990  IF EC = 254 THEN AN$ = "PROBABLE CAUSE: RESPONSE TO A DATA PROMPT M
     ADE IMPROPERLY.  PLEASE NOTE THE REQUIRED FORMAT OF THE DATA (SEE USE
     R'S INSTRUCTIONS).": GOSUB 3050
3000  IF EC = 5 THEN AN$ = "PROBABLE CAUSE: YOU SPECIFIED A SAMPLE NUMBER
      WHICH DOES NOT EXIST (I.E. HAS NOT BEEN STORED ON DISK)": GOSUB 305
     0
3010  PRINT : PRINT
3020  GOTO 1120
3030  REM


3040  REM
  THE FOLLOWING TWO SUBROUTINES HAVE BEEN EXTRACTED FROM THE '
     MAGIC MENU ' PROGRAM PUBLISHED BY APPLE COMPUTER INC. (SLIGHT ALTERA
     TIONS HAVE BEEN MADE)


3050  REM *** SCREEN FORMATTER ***

3060  REM STRING TO BE PRINTED IN AN$
3070  REM IF 80 COLUMN BOARD IS TURNED ON, MAKE SURE COL80 = 1.  IF BOARD
      IS NOT TO BE USED, MAKE SURE COL80 = 0.
3080  REM USES I,J,I$
3090  REM ROUGH EQUIVALENT OF  PRINT AN$;" ";
3100  REM  USES AIIE SET BY COMPUTER IDENTIFIER ROUTINE
3110  REM USUALLY LEAVES 1 EXTRA BLANK AT END OF LINE
3120  REM PERFORMS WORD-WRAP AND WILL CONVERT LOWER- TO UPPER-CASE IF USE
     D INSIDE AN APPLE II OR II+
3130 I =  LEN (AN$): IF  NOT I THEN  RETURN
3140 P =  PEEK (36): IF COL80 THEN  IF P =  PEEK (1147) THEN P =  PEEK (1
```

```
     403): REM FIND CURRENT HORIZ POSITION WITH 80 COLUMN CARD TURNED ON
3150  IF  NOT P THEN  IF I > 1 THEN  IF  ASC (AN$) = 32 THEN AN$ =  RIGHT$
     (AN$,I - 1)
3160  IF P + 2 + I <  PEEK (33) AND AIIE THEN  PRINT AN$;" ";:AN$ = "": RETU
     : REM EXPRESS CHECK-OUT
3170  IF I > 1 THEN  IF  RIGHT$ (AN$,1) = " " THEN AN$ =  LEFT$ (AN$,I -
     1)
3180  IF P + I <  PEEK (33) THEN I$ = AN$:AN$ = "": GOTO 3240
3190 J =  PEEK (33) - P + 2:I = J
3200 I = I - 1: IF I THEN  IF  MID$ (AN$,I,1) <  > " " THEN 3200
3210  IF I = 1 THEN I = J
3220  IF I = 0 THEN  PRINT : GOTO 3130
3230 I$ =  LEFT$ (AN$,I - 1): IF  LEN (AN$) > I THEN AN$ =  RIGHT$ (AN$, LEN
     (AN$) - I): REM ISOLATE 1 LINE IN I$
3240  IF AIIE THEN  PRINT I$;
3250  IF  NOT AIIE THEN K =  LEN (I$) + 1: FOR I = 1 TO  LEN (I$):J =  ASC
     ( RIGHT$ (I$,K - I)): PRINT  CHR$ (J - 32 * (J > 96 AND J < 123));: NEX
     I
3260 P =  PEEK (36): IF COL80 THEN  IF P =  PEEK (1147) THEN P =  PEEK (1
     403)
3270  IF  LEN (AN$) THEN  IF P <  > 0 THEN  PRINT
3280  IF  LEN (AN$) THEN 3130
3290  IF P <  > 0 THEN  IF  MID$ (I$, LEN (I$),1) <  > " " THEN  PRINT "
     ";
3300  RETURN
3310  REM



3320  REM *** COMPUTER ID ***
3330  REM *** AIIE OR NOT? ***
3340  REM  USES I,J,K,RE  -- SETS AIIE TO 1 IF IT IS AN AIIE
3350  REM SETS RESULT DEPENDENT ON AVAILABLE HARDWARE
3360  REM RESULTS OF 0 MEANS NOT A //E; 32 MEANS A//E BUT NO 80 COLUMNS;
     64 MEANS A//E WITH 80 COLUMNS BUT NO AUX MEM; 128 MEANS A//E WITH AU
     X MEM
3370  DATA  8, 120, 173, 0, 224, 141, 208, 2, 173, 0, 208, 141, 209, 2, 1
     73, 0, 212, 141, 210, 2, 173, 0, 216, 141, 211, 2, 173, 129, 192, 17
     3, 129, 192, 173, 179, 251, 201, 6, 208, 73, 173
3380  DATA  23, 192, 48, 60, 173, 19, 192, 48, 39, 173, 22, 192, 48, 34,
     160, 42, 190, 162, 3, 185, 0, 0, 150, 0, 153, 162, 3, 136, 208, 242,
      76, 1, 0, 8, 160, 42, 185, 162, 3, 153
3390  DATA  0, 0, 136, 208, 247, 104, 176, 8, 169, 128, 141, 207, 3, 76,
     73, 3, 169, 64, 141, 207, 3, 76, 73, 3, 169, 32, 141, 207, 3, 76, 73
     , 3, 169, 0, 141, 207, 3, 173, 0, 224
3400  DATA  205, 208, 2, 208, 24, 173, 0, 208, 205, 209, 2, 208, 16, 173,
      0, 212, 205, 210, 2, 208, 8, 173, 0, 216, 205, 211, 2, 240, 56, 173
     , 136, 192, 173, 0, 224, 205, 208, 2, 240, 6
3410  DATA  173, 128, 192, 76, 161, 3, 173, 0, 208, 205, 209, 2, 240, 6,
     173, 128, 192, 76, 161, 3, 173, 0, 212, 205, 210, 2, 240, 6, 173, 12
     8, 192, 76, 161, 3, 173, 0, 216, 205, 211, 2
3420  DATA  240, 3, 173, 128, 192, 40, 96, 169, 238, 141, 5, 192, 141, 3,
      192, 141, 0, 8, 173, 0, 12, 201, 238, 208, 14, 14, 0, 12, 173, 0, 8
```

```
    , 205, 0, 12, 208, 3, 56, 176, 1, 24
3430  DATA  141, 4, 192, 141, 2, 192, 76, 29, 3, 234
3440 J = 975:K = 724
3450  FOR I = 0 TO 249
3460  READ L
3470  POKE K + I,L
3480  NEXT
3490  CALL K
3500 RESULTS =  PEEK (J)
3510  IF RESULTS <  > 0 THEN AIIE = 1
3520  RETURN
3530  REM


3540  REM  ====<SUBROUTINE TO RETRIEVE DATA FROM DISK>====
3550  REM   THE NAME OF THE DATA FILE IS STORED IN N$ (NL$ IS N$ WITH A L
    ENGTH PARAMETER)
3560  REM   (FILE IS RANDOM ACCESS, FIELD LENTH 30, WITH RECORD NUMBERS C
    ORRESPONDING TO THE SAMPLE NUMBERS)
3570  PRINT D$;"LOCK";N$
3580  PRINT D$;"OPEN";NL$
3590  PRINT D$;"READ";N$;",R";N
3600  INPUT N,T,DO,BP,DP
3610  PRINT D$;"CLOSE";N$
3620  RETURN
```

References

Byres, R.D. and J.A. Servizi (1986). Dissolved Atmospheric Gases and Reaeration Coefficients for the Nechako River.

Servizi, J.A. (1981). Estimation of Reaeration coefficients for the Nechako River. IPSFC Data Analysis, Part II. (Unpubl.) January 1981. 8pp

APPENDIX 12

EXAMPLE HAND CALCULATIONS - K_2 COEFFICIENTS

TRIP 1, REACH 2, PAIR (15,18)

Cutoff: $[N_2+Ar] = 17.61\ mgL^{-1}$ $[N_2+Ar]sat = 16.96$ Temp. = 11.7°C
Greer: $[N_2+Ar] = 17.05$ $[N_2+Ar]sat = 15.73$ Temp. = 15.1°C

travel time = 7.75 hours

Assume $k_2 = 0.020$

$$d = (16.96 - 15.73)(1 - 10^{-(0.02)(7.75)})$$
$$= (1.23)(0.3002) = 0.3692$$

temperature has <u>increased</u> therefore <u>add</u> value of d to $[N_2+Ar]_{Greer}$

$[N_2+Ar] = 17.05 + 0.369 = 17.42\ mgL^{-1}$

$$S_1 = \frac{17.42}{16.96}(100) = 102.708\% \qquad S_0 = \frac{17.61}{16.96}(100) = 103.833\%$$

$$k_2 = -\frac{1}{7.75}\log\frac{(2.708)}{(3.833)} = \underline{0.0195}$$

Try $k_2 = 0.0198$

$$d = (1.23)(1 - 10^{-0.0198(7.75)}) = 0.366$$

$[N_2+Ar] = 17.05 + 0.366 = 17.42$

$$S_1 = \frac{17.42}{16.96}(100) = 102.662 \qquad S_0 = 103.833$$

$$k_2 = -\frac{1}{7.75}\log\frac{(2.662)}{(3.833)} = 0.01985$$

- close enough to 0.0198

therefore $k_2 = 0.0198\ hr^{-1}$

.... cont

EXAMPLE HAND CALCULATIONS, cont.

Conversion to 20°C and base e:

average temperature on reach = 1/2(11.7 + 15.1) = 13.4°C

$$k_2(20°C) = \frac{0.0198}{1.024^{(13.4-20)}} = 0.0232 \text{ hr}^{-1}$$

$$K_2(20°)e = \frac{k_2(20°)_{10}}{\log_{10}(e)} = \frac{0.0232}{0.43429}$$

$$= 0.0533 \text{ hr}^{-1}$$

therefore, $K_2(20°)e = 0.0533 \text{ hr}^{-1}$, pair (15,18)

(Note that the above method is quite amenable to solution by hand calculator or computer using root-finding algorithms such as the secant method, etc.)

APPENDIX 13

NECHAKO RIVER DISSOLVED GAS DATA, JUNE 1985

SAMPLE NO.	SITE	DATE day/mo.	TIME 24 hr.	DO mgL^{-1}	BP mmHg	Δ P mmHg	TEMP °C	%TGP (moist)	N_2+Ar mgL^{-1}	N_2+Ar (Sat)+ mgL^{-1}
1	1	15/6	0935	9.95	697.5	19	12.5	102.7	16.86	16.36
2	2	15/6	1100	10.25	702.8	48	12.4	106.8	17.81	16.52
3	2	15/6	1200	10.50	703.0	47	13.3	106.7	17.25	16.22
4	2	15/6	1300	10.40	703.2	47	12.8	106.7	17.53	16.39
5	F	15/6	1410	8.20	703.4	20	15.0	102.8	16.76	15.68
6	3	15/6	1630	10.40	705.7	48	14.4	106.8	16.91	15.92
7	3	15/6	1730	10.25	706.0	50	14.5	107.1	17.00	15.99
8	3	15/6	1830	10.20	705.8	47	14.2	106.7	17.99	17.31
9	3	16/6	0800	10.25	710.0	20	10.7	102.8	17.95	17.19
10	3	16/6	0900	10.40	709.7	26	11.0	103.7	18.01	16.97
11	3	16/6	1000	10.45	709.9	38	11.6	105.4	17.08	15.86
12	4	16/6	1645	10.20	707.2	54	14.7	107.6	17.01	15.77
13	4	16/6	1745	10.20	707.2	56	15.0	107.9	16.95	15.67
14	4	16/6	1845	10.15	707.1	58	15.3	108.2	17.61	16.96
15	3	17/6	0800	10.20	710.8	22	11.7	103.1	17.60	16.85
16	3	17/6	0900	10.30	710.6	29	12.0	103.9	17.61	16.65
17	3	17/6	1000	10.30	709.7	37	12.5	105.2	17.65	15.73
18	4	17/6	1545	10.00	707.0	56	15.1	107.9	16.92	15.54
19	4	17/6	1645	10.00	706.6	61	15.7	108.6	16.72	15.40
20	4	17/6	1745	9.95	705.8	60	16.1	108.5	16.15	15.35
21	8	18/6	1130	9.85	707.7	42	16.4	105.9	16.18	15.27
22	8	18/6	1230	9.95	706.6	47	16.6	106.7	15.77	14.92
23	8	18/6	1330	10.40	705.4	57	17.7	108.1	15.94	15.11
24	5	18/6	1500	9.50	702.0	39	16.8	105.6	15.81	14.95
25	5	18/6	1600	9.45	701.4	41	17.3	105.8	15.71	14.84
26	5	18/6	1700	9.45	701.6	43	17.7	106.1	15.75	15.22
27	9	19/6	0900	9.15	704.6	21	16.6	103.0	15.75	15.22
28	9	19/6	1000	9.15	704.3	25	17.0	103.5	15.70	15.10
29	9	19/6	1100	9.25	704.2	28	17.4	104.0	15.58	14.98
30	7	19/6	1400	9.80	699.9	33	18.6	104.7	14.90	14.55
31	6	19/6	1500	9.50	699.2	37	16.0	105.3	16.13	15.28
32	6	19/6	1600	9.45	699.6	38	16.0	105.4	16.19	15.29
33	6	19/6	1700	9.45	699.6	33	15.8	104.7	16.13	15.35
34	8	20/6	0912	9.15	706.5	06	15.5	100.8	15.82	15.60
35	8	20/6	1012	9.45	706.0	12	15.8	101.7	15.72	15.49
36	8	20/6	1112	9.75	705.9	25	16.3	103.5	15.75	15.34

+ saturation concentration

Site 1 - Above Cheslatta Falls
Site 2 - Below Cheslatta Falls
Site F - Nechako Canyon below Kenny Dam
Site 3 - Cutoff Creek
Site 4 - Greer Creek
Site 5 - Fort Fraser
Site 6 - Nautley River
Site 7 - Nechako above Nautley
Site 8 - Vanderhoof
Site 9 - Finmoore

APPENDIX 14

NECHAKO RIVER DISSOLVED GAS DATA, AUGUST 1985

SAMPLE NO.*	SITE	DATE day/mo.	TIME	DO mgL^{-1}	BP mmHg	Δ P mmHg	TEMP °C	%TGP (moist)	N_2+Ar mgL^{-1}	N_2+Ar (Sat)+ mgL^{-1}
D**	2	2/8	1115	-	700.0	91	16.0	113.0	-	-
100	2	8/8	0900	9.70	699.4	70	16.5	110.0	16.77	15.14
101	2	8/8	1000	9.85	699.3	72	16.6	110.3	16.71	15.11
102	2	8/8	1100	9.80	699.0	84	16.5	112.0	17.10	15.13
103	3	8/8	1254	10.10	699.6	96	17.3	113.7	16.98	14.91
104	3	8/8	1354	10.10	699.0	95	17.3	113.6	16.94	14.90
105	3	8/8	1454	10.10	699.1	94	17.2	113.4	16.96	14.93
106	4	8/8	1824	9.75	698.1	80	17.6	111.5	16.54	14.79
107	4	8/8	1924	9.65	698.4	78	17.5	111.2	16.58	14.83
108	4	8/8	2024	9.60	698.8	75	17.3	110.7	16.61	14.89
109	5	9/8	0912	8.80	702.9	18	16.6	102.6	15.78	15.18
110	5	9/8	1012	8.80	702.4	18	16.6	102.6	15.76	15.17
111	5	9/8	1112	9.85	702.6	18	16.5	102.6	15.34	15.21
112	2	10/8	1045	10.40	705.4	105	16.2	114.9	17.73	15.36
113	2	10/8	1145	10.35	705.6	106	16.2	115.0	17.79	15.36
114	2	10/8	1245	10.20	705.1	107	16.3	115.2	17.83	15.32
115	3	10/8	1440	10.35	705.8	95	16.8	113.5	17.23	15.19
116	3	10/8	1540	10.30	705.8	93	16.6	113.2	17.28	15.25
117	3	10/8	1640	10.20	705.8	89	16.4	112.6	17.30	15.31
118	6	11/8	0800	8.95	706.5	-8	14.8	98.9	15.79	15.82
119	6	11/8	0900	9.50	706.9	-1	14.8	99.9	15.76	15.82
120	6	11/8	1000	9.85	706.8	10	15.1	101.4	15.79	15.73
122	7	12/8	0820	8.50	710.1	10	15.9	101.4	16.37	15.56
123	7	12/8	0920	8.30	709.8	4	15.9	100.6	16.07	15.55
124	7	12/8	1020	8.70	709.6	6	16.1	100.8	15.87	15.48
125	6	12/8	1100	10.10	709.1	10	15.1	101.4	15.74	15.78
126	8	12/8	2315	8.85	709.8	11	17.0	101.5	15.60	15.22
127	8	13/8	0015	8.75	709.8	8	16.8	101.1	15.64	15.28
128	8	13/8	0115	8.75	710.0	6	16.7	100.8	15.62	15.31
129	9	13/8	1530	9.05	707.7	21	18.0	103.0	15.34	14.89
130	9	13/8	1630	9.05	707.7	22	17.9	103.1	15.41	14.91
131	9	13/8	1730	9.00	707.1	20	17.9	102.8	15.36	14.90

+saturation concentration

*samples were numbered consecutively with the June '85 samples numbered 1-36 and the August samples numbered 100-131. The starting numbers were arbitrary and there were no samples in the range 37-99, nor was there a sample numbered 121.

**sample D was unnumbered and collected as part of a separate experiment (Rowland, 1986).

APPENDIX 15

"MIXING" CRITERIA AT NAUTLEY NECHAKO CONFLUENCE

SURVEY #1 (JUNE 1985)

	FLOW ft^3s^{-1}	$[N_2+Ar]$ mgL^{-1}	$[N_2+Ar]$ sat mgL^{-1}	Temp. °C	Sample #
NECHAKO	(2070)	14.9	14.55	18.6	30
		16.13	15.28	16.0	31
NAUTLEY	2380	16.19	15.29	16.0	32
		16.13	15.35	15.8	33
TOTAL	4450	15.56	14.94	17.2	31/30
		15.58	14.95	17.2	32/30
		15.56	14.98	17.1	33/30

NAUTLEY FLOW; based on 19/6/85 reading at Nautley guage
TOTAL FLOW; based on 19/6/85 reading at Vanderhoof guage
NECHAKO FLOW; based on (Total)-(Nautley)
(assumes contribution from tributaries other than Nautley are negligible)

Concentration and temperature values for "Total" flow are a flow-weighted average. These values are combined with those from samples 34, 35, 36 to produce a K_2 for the Nautley-Vanderhoof reach.

Similarly, for SURVEY #2; (August 1985) (combine 125 with 126, 127, 128)

	FLOW ft^3s^{-1}	$[N_2+Ar]$ mgL^{-1}	$[N_2+Ar]$ sat mgL^{-1}	Temp. °C	Sample #
NECHAKO	(10185)	16.37	15.56	15.9	126
		16.07	15.55	15.9	127
		15.87	15.48	16.1	128
NAUTLEY	833	15.74	15.78	15.1	125
TOTAL	11018	16.32	15.57	15.8	126/125
		16.05	15.57	15.8	127/125
		15.86	15.50	16.0	128/125

APPENDIX 16

EXAMPLE OF FLOW-WEIGHTED MIXING ADJUSTMENT

Nechako River and Nautley River merge and move downstream, therefore initial conditions of reach 4a samples should be a weighted mean of the two rivers.

eg. June 1985, Samples 30, 31
Nautley flow was greater than Nechako, therfore take 3 samples on Nautley, 1 on Nechako. (Due to time constraints it was impossible to sample three times on both rivers.)

	FLOW ft^3s^{-1}	$[N_2+Ar]$ mgL^{-1}	Temp. °C
NAUTLEY	2380	16.13	16.0
NECHAKO	2070	14.9	18.6

$$\text{Combined Temp.} = \frac{(16.0)(2380) + (18.6)(2070)}{2380 + 2070} = 17.2°C$$

$$\text{Combined } [N_2+Ar] = \frac{(16.13)(2380) + (14.9)(2070)}{2380 + 2070} = 15.56 \text{ mgL}^{-1}$$

and $[N_2+Ar]$sat, based on 17.2°C = 14.94 mgL^{-1}

APPENDIX 17

Sensitivity of K_2 to travel time variability

Reach 1, 62.3 m^3s^{-1} (2200 ft^3s^{-1}), data pair (2,6)

$[N_2]_0$ = 17.81 mgL^{-1} $[N_2]sat_0$ = 16.53 mgL^{-1} T_0 = 12.4°C

$[N_2]_1$ = 16.91 mgL^{-1} $[N_2]sat_1$ - 15.93 mgL^{-1} T_1 = 14.4°C

travel time	$K_2(20)_e$	% Change
5.5 hours (original case)	0.1379	-
5.5 + 10% = 6.05 hours	0.1254	-9.1%
5.5 - 10% = 4.95 hours	0.1533	+11.2%

ie. error in K_2 inversely proportional to error in travel time.

APPENDIX 18

Sensitivity of K_2 to temperature measurement.

Reach 1, 62.3 m^3s^{-1} (2,200 ft^3s^{-1}), data pair (2,6)

ORIGINAL DATA

$[N_2+Ar]_0 = 17.81\ mgL^{-1}$ $[N_2+Ar]sat_0 = 16.53\ mgL^{-1}$ $T_0 = 12.4°C$

$[N_2+Ar]_1 = 16.91\ mgL^{-1}$ $[N_2+Ar]sat_1 = 15.93\ mgL^{-1}$ $T_1 = 14.4°C$

Travel time 5.5 hours
$K_2(20)_e = 0.1379$

For errors of 0.2 and 0.5°C respectively:

CASE	CHANGE MADE	% Temp. Change	$K_2(20)e$	%Change, $k_2(20)$
1	$T_0 = 12.6°$	1.6%	0.1267	-8.1%
2	$T_0 = 11.9°$	-4.0%	0.1644	19.2%
3	$T_1 = 14.2°$	-1.4%	0.1257	-8.8%
4	$T_1 = 14.9°$	3.5%	0.1675	21.5%

From the above results it is evident that an error in the measurement of temperature can have a larger effect on the value of $K_2(20)_e$ calculated.